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A comparative study of the subspecies of Sclerocarya birrea
Their potential for domestication in Tanzania

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A comparative study of the subspecies of *Sclerocarya birrea*:
Their potential for domestication in Tanzania

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ABSTRACT

Sclerocarya birrea, commonly known as Marula, has three subspecies with Tanzania being the only country where all subspecies co-exist. This study was done to assess and compare local knowledge, population status, phenology and propagation of the three subspecies. Three sites located north to south of the country were selected for the study. Each of the three sites namely Holili village (North), Kiegea village (East-Central) and Malinzanga village (South) represented one of the subspecies. Local knowledge was assessed by administering a total of 323 questionnaires to at least 20% of the household heads in each study villages. Direct Observations, Key Informants Interviews and PRA were also used to collect data. Study of population status and regeneration of *Sclerocarya birrea* involved sampling of two landuse types at each village i.e. wild and on farm environment using the plotless sampling technique. Each plot consisted of 100 nearest neighbour *Sclerocarya* trees from which dendrometric variables (height, dbh, height to first branch and crown diameter) were measured. At each plot, 10% of 20 m x 20 m plots were used to assess regeneration status. Species associated with *Sclerocarya* were also identified and counted at each site. Ten female and ten male trees randomly selected from each site were used for the phenology study from which detailed events of leafing, flowering and fruiting onsets and durations were recorded. Fruits were counted from under the 10 female trees and diameter and weight of 50 fruits selected randomly from each of the 10 female trees were measured. Cuttings, marcoting and grafting experiments were conducted to test for the most practical and cost-efective propagation method to farmers under their local environmental realities. It was found that although farmers consider marula as an important species and own it on their farms, the species is underutilized in Tanzania due to some institutional barriers. Results from the population study revealed that the on farm population for subspecies *caffra* was denser than all other populations. For the other two subspecies the wild populations were denser than their respective on-farm population. Abundance of male trees was higher than female trees for all subspecies and environments. Spatial distribution for all the populations was random with **R** values close to 1.0, meaning that observed distribution ($\mathbf{r_o}$) was close to the expected distribution ($\mathbf{r_e}$). Male trees were significantly bigger than females. Coppicing from stumps and sprouting from roots were the main form which the population of *Sclerocarya birrea* is recruited. All aspects of phenology varied by subspecies, land-use, gender and weather with the exception of flowering and fruiting which did not vary with land-use. Results showed that subspecies *multifoliolata* had significantly heavier fruits and more yield than subspecies *birrea* and *caffra* ($p < 0.001$). Fruits from subspecies *birrea* were significantly larger than those from the other two subspecies ($p < 0.001$).Trees from the wild population yielded more fruits that were also heavier than those from on-farm but the difference was only significant for subspecies *multifoliolata* ($p < 0.001$). Results showed that fruit physical properties and yield have allometric relationship with tree size structure and they vary with rainfall and type of subspecies but not with farmers' selection pressure and intervention. Propagation by cuttings and air layering of *Sclerocarya birrea* failed. Grafting at the beginning of the rain seasons using wild root stock resulted into 99% success and fruiting after just two years. This study concludes that, if *Sclerocarya birrea* is domesticated in Tanzania it can contribute to food security, income generation and environmental conservation. The government, NGOs and researchers have a key role to play in helping farmers to improve the management and utilization of marula.

DEDICATION

- To my father, Andrew Woiso and mother, Teresia Woiso who taught me the importance of Education

- To my lovely wife Betty and wonderful children Kent and Novia, you are my daily happiness.

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ABREVIATIONS AND ACRONYMS

AFREA	Association of Forest Research Institutions in East Africa
ANOVA	Analysis of Variance
CI	Confidence Interval
CIFOR	Centre for International Forestry Research
DBH	Diameter at Breast Height
DF	Degrees of Freedom
DFID	Department for International Development
DM	Dry Matter
DNA	Deoxyribonucleic Acid
DRC	Democratic Republic of Congo
FAO	Food and Agricultural Organisation
GIS	Geographic Information System
GPS	Global Positioning System
ICRAF	International Centre for Research in Agroforestry (Now – World Agroforestry Centre)
IFT	Indigenous Fruit Trees
IPGR	International Plant Genetic Resources Institute (Now – Biodiversity International)
KIWILI	Kusaidiana Kazi (English – Working together)
LS	Loamy Sand
MIBS	Men in Black
MNRT	Ministry of Natural Resources and Tourism
NND	Nearest Neighbour Distance
NGO	Non Governmental Organisation
NTFP	Non Timber Forest Products
PCR	Polymerase Chain Reaction
pH	Power of Hydrogen
PRA	Participatory Rural Appraisal
RAPD	Random Amplification of Polymorphic DNA
SAFORGEN	sub-Saharan African Forest Genetic Resources
SCL	Sandy Clay Loam
SE	Standard Error
SL	Sandy Loam
SEPASAL	Survey of Economic Plants for Arid and Semi-Arid Lands
SIDA	Swedish International Development Cooperation Agency
SLU	Sveriges lantbruksuniversitet (English– Swedish University of Agricultural Sciences)
SPSS	Statistical Package for Social Scientists
SUA	Sokoine University of Agriculture
TG	Top Grafting
TMA	Tanzania Meteorological Agency
TW	Top Wedge
UK	United Kingdom
USA	United States of America
USDA	United Stated Department of Agriculture
US$	United States Dollar
UTM	Universal Transverse Mercator
W&T	Whip and Tongue

CHAPTER ONE: INTRODUCTION

1.1 Background

The economic and nutritional importance of indigenous fruit trees has been identified and described by many researchers (Maghembe *et al.,* 1994; Leakey & Simons, 1998; DFID, 2003; Leakey, 2005; Teklehaimanot, 2005; Akinnifesi *et al.,* 2006; Teklehaimanot, 2008) Leaving little doubt that indigenous fruit trees play a vital role in food and nutritional security, especially during periods of famine and food scarcity in areas of rural Africa (Saka *et al.,* 2002, 2004, Akinnifesi *et al.,* 2004), and suggesting they are becoming increasingly important as a main source of food to supplement diets in better times. The fundamental importance of indigenous fruit trees is their provision of vital nutrients and vitamins as supplements to the cereal staples which commonly dominate rural African meals. The timing of fruit production is also mportant when it coincides with seasonal periods of food scarcity. Their fruits can be sold raw or as processed products to contribute income to the household. Indigenous fruit trees which are normally retained by farmers when opening up forests for agriculture are also important in maintaining a favorable microclimate and lessening the effects of climate change. Therefore these trees are an important asset to rural community, the environment and have great potential in revolutionizing the economies of rural people and their respective nations.

However their importance remains largely theoretical because of the lack of sufficient consideration by research and development practitioners. A lot more work needs to be done to collect empirical information about the trees and how their contribution to the economy and the environment can be assessed and monitored. Issues of uniformity in terms of quality and quantity of fruits, fair and attractive pricing by the markets and integration into appropriate farming schemes also needs to be resolved. Immediate interventions are needed to avoid the loss of potentially important provenances through the increased demand for forest resources and land for other human uses (Scoones *et al.,* 1992; Teklehaimanot, 2004).

Tanzania has the richest diversity of plant species than other African countries with exception of the Democratic Republic of Congo (DRC) and South Africa (Ruffo *et al.*, 2002). It is estimated that there are about 9,000 species of plants in Tanzania that can be found in five phytogeographical regions, namely Afro-montane, Lake Victoria, Somali-Maasai, the Zambezian and the Zanzibar-Inhambane. All these regions are rich in biodiversity, now often restricted to hotspots due to human activities (Ruffo *et al.*, 2002). Biodiversity in these regions has historically played a major role in human daily lives; as the source of products such as timber, poles, fuelwood, fodder, medicine, bees' wax, honey and edible indigenous fruits (MNRT, 1998; Swai, 2001; Ruffo *et al.*, 2002). Various surveys and research activities conducted on indigenous fruits across Tanzania have identified about 700 tree species available and utilized in the country (Lindström and Kingamkono, 1991; Hines and Eckman, 1993; Buwalda *et al.*, 1997; Ramadhani *et al.*, 1998; Ruffo *et al.*, 2002), of which 200 are edible (Akinnifesi *et al.,* 2008a). Some of the trees presented in table 1.1.

Table 1. 1: A list of some indeginous fruit species used in Tanzania

Scientific name	Common name	Scientific name	Common name
Parinari curatellifolia	Hissing tree	*Kigelia africana*	Sausage tree
Adansonia digitata	Baobab	*Lannea schweinfurthii*	False marula
Allanblackia stuhlmannii	Mkani	*Olea europaea*	Olive tree
Annona senegalensis	Wild soursop	*Pachystella msolo*	Msambia
Azanza garckeana	African chewing gum	*Parinari excelsa*	Sausage
Balanites aegyptiaca	Desert date	*Rhus natalensis*	Natal rhus
Berchemia discolor	Mountain date	*Sclerocarya birrea*	Marula
Boscia mossambicensis	Shepherds tree	*Salvadora persica*	Mustard tree
Bridelia micrantha	Coast goldleaf	*Solanum incanum*	Bitter apple
Commiphora africana	African myrrh	*Sorindeia madagascariensis*	Mtikiza
Cordia africana	Eat African cordia	*Strychnos cocculoides*	Corkey-monkey orange
Vitex doniana	Black plum	*Strychnos innocua*	Monkey orange
Cordia sinensis	Grey-leaved saucer-berry	*Syzygium cordatum*	Water berry
Diospyros kirkii	Large-leaved jackal-berry	*Syzygium guineense*	Snake bean tree
Diospyros mespiliformis	Jackal berry	*Tamarindus indica*	Tamarind
Euclea divinorum	Magic gwarra	*Trema orientalis*	Pegion tree
Ficus sycomorus	Sycamore	*Uapaca kirkiana*	Wild loquat
Flacourtia indica	Ramontchi	*Vangueria infausta*	Wild medlar
Grewia bicolour	False brandybush	*Vangueria madagascariensis*	Spanish tamarind
Grewia platyclada		*Vitex mombassae*	Sungwi
Ilex mitis	African Holly	*Vitex payos*	Chocolate berry

These species are found in a wide range of vegetation from the lowland to the mountainous areas. They have been described as 'Cinderella species' which have been overlooked by science and development (Leakey & Newton, 1994; Akinnifesi *et al.,* 2008a). Recent efforts show that the trees represent a unique asset that could be developed, domesticated and owned by farmers. Since the 1990s, domestication of indigenous fruit trees in sub-Saharan Africa has become a new and active field of research and development although effeorts are still insufficient. New concepts and approaches have been developed, case studies have been produced, and evidence-based research is being undertaken on the potential and feasibility of domesticating indigenous fruit trees as well as commercializing their products (Akinnifesi *et al.,* 2008a).

As an initial step for domestication purposes, particularly in the Miombo woodland areas, priority species for domestication have been identified using participatory approaches (Akinnifesi *et al.,* 2002; Teklehaimanot, 2005; AFREA, undated). Following on the approach used by the Association of Forest Research Institutions in East Africa (AFREA), Teklehaimanot (2005) came up with a list of priority species in East Africa. His approach was based on two main stages; firstly discussions and priority setting in collaboration with national level forest experts and secondly field assessment by involving farmers to select priority species. His work resulted in a varied ranking of priority species for each of the five surveyed countries. The most important species were *Sclerocarya birrea* (Tanzania), *Balanites egyptiaca* (Sudan), *Cordeauxia edulis* (Ethiopia), *Vitellaria paradoxa* (Uganda) and *Vitex payos* (Kenya). Jama *et al.* (2008) describes 'the big five'; important fruit species that are cross-regional: *Adansonia digitata*, *Tamarindus indica*, *Zizyphus mauritiana*, *Sclerocarya birrea*, and *Mangifera indica. Sclerocarya birrea* is included in both lists indicating its wide range of significance.

These priority species are known to have potential for wider use and could contribute significantly to the improvement of agricultural systems (Teklehaimanot, 2008). Their fruits are not only important sources of food and income for the community, but also serve as strategic food reserves during season of food shortages (Kadzere *et al.*, 1998; Iddi 1998; Swai, 2001; Ruffo *et al.*, 2002, Teklehaimanot, 2008). As most of them are found to ripen at different seasons, they compensate for variations in nutrient intake from green leafy vegetables and cultivated fruits (Lindström & Kingamkono, 1991; Hines and Eckman, 1993 and Kwesiga *et al.*, 2000). The food source may originate from fruits, seeds, nuts or pulp which contains vital nutrients and essential vitamins that are especially important to growing children who are often prone to malnutrition and related diseases (Kadzere *et al.*, 1998 and Ndabikunze *et al.*, 2000). For example, *Sclerocarya birrea* which has a juicy pulp, may be eaten raw, made into refreshing juice by soaking in water and adding sugar, or nuts removed from the hard kernel and consumed as a snack (Swai *et al.*, 2001; Ruffo *et al.*, 2002; Hall *et al.*, 2002; DFID, 2003). Apart from being consumed as food, fruit species; have been reported to provide other uses such as livestock feeds, crafts, medicines, firewood, timber, charcoal, carvings, and a number of ecosystem services such as carbon sequestration. (Ramadhani *et al.*, 1998, Teklehaimanot, 2008).

Sclerocarya birrea known commonly as Marula is a dioecious multipurpose fruit tree that occurs in the semi-arid, deciduous savannas across the region of sub-Sahara Africa (Kokwaro & Gillet, 1980; Hall *et al.*, 2002; ICRAF, 2005). Known as marula, its natural range in the region spreads from 0 to 1800 m above mean sea level, with habitat varying from dry and rocky hillsides to riparian environment, though it is most common on rocky sites with sandy to sandy clay soils. The tree is a medium to large (7-20m high), deciduous, with a wide crown and characteristic silvery, mottled bark, peeling in disc-shaped flakes (Palmer and Pitman, 1972). The small dark red flowers are unisexual and found in fragrant clusters at the end of the branches. The compound leaves are grey-green in colour, but turn pale yellow prior to being shed. Denuded of leaves, the top branches appear abnormally thick and erect, like upturned fingers (digitaliform). The leaves attract many butterflies, including the green lunar moth, whose large silkworm-like cocoons are used by Southern Africans as ankle rattles for dancing. The tree remains bare for several months of the year (Watt and Breyer-Brandwijk, 1962).

The Marula tree is in the same family, Anacardiaceae, as the mango, cashew and pistachio nut. The plum sized fruits are covered in a soft, leathery, pale green-yellow exocarp which encloses the juicy white flesh (Hall *et al.*, 2002). The fruit has an exotic flavour and a distinctive scent. The fruit contains a large hard seed, surrounding two or more edible kernels, rich in oil. Marula trees are distinctive for their exceptional fruit and nut yields, making them very easy to harvest. In fact this characteristic has not only been noted by humans, but also by elephants that will travel miles to gorge on the fruits (Hutchings *et al.,* 1996). Importantly, the Marula fruit harvest occurs at the beginning of the school year making the cash income from their sale very important for the payment of school fees and clothing (Wynberg *et al.,* 2003).

Sclerocarya birrea has for decades played an integral part in the lives, food security and spirituality of indigenous local communities in sub-Saharan Africa (Shackleton *et al.,* 2000). The species has a wide variety of uses including the consumption of the fresh fruit, use of the fresh fruit to make juice, jam and beer, use of the kernels as a food source and as a flavouring and preservative for other foods, use of bark for medicinal purposes, and the use of the wood for firewood and carvings (Shackleton *et al.,* 2002; Hall *et al.,* 2002). However, the fruit is the most important asset of *Sclerocarya birrea.* The fruit of *S. birrea,* while contributing to rural diets, with higher levels of vitamin C than orange, grapefruit and mango, also has a potentially large economic value. It is the only Miombo fruit species to make it through to the international market (Akinnifesi *et al.,* 2008a). The fruits are used to make Amarula, the second most marketable cream liquor after the Irish Baileys cream, available in many countries across the world and recently breaking into the United States market. In terms of direct-use value to local communities, households within rural villages in one region in South Africa (approximately 80,000 households) collect an average of 1.2 tonnes of fruit per season. Much of this goes to brewing a low alcohol beverage (Shackleton and Shackleton, 2005). Adding in home consumption of kernels, jam, fresh fruit, firewood, and medicine from the bark, the direct-use value to households is significant. Additionally, there has been a growing trade in *S. birrea* products, mainly by women, paralleling the growing commercialization of wild resources throughout southern Africa (Brigham *et al.,* 1996; Mander, 1998; Braedt & Standa-Gunda, 2000; Shackleton *et al.,* 2000). This trade in marula products has been both self-initiated, as well as promoted by external organization and institutions.

Although *Sclerocarya birrea* is extremely useful, found in many parts of Africa; and Tanzania being the centre of its diversity (Kadu *et al.,* 2006; Chirwa & Akinnifesi, 2008a); little has been done to maximize benefits to farmers from the vast potentials held by the tree. Tanzania is regarded as the centre of diversity for *S. birrea* because it is the only country where all three subspecies are found and wild populations are the most genetically diverse (Kadu *et al.,* 2006). Subspecies *birrea* is found in the northern part of the country while *cafra* and *multifoliolata* are found in the central and southern parts, respectively. Subspecies *multifoliolata* is found in Tanzania only and because past research on *Sclerocarya* has been conducted outside Tanzania, little information exists on subspecies *multifoliolata*. The present research was, therefore, conducted in Tanzania to compare the three subspecies of *S. birrea* by studying them simultaneously, an approach never used before.

Existing information on *Sclerocarya birrea* is mostly from areas outside Tanzania focusing on subspecies *birrea* and *cafra*, individually covering few aspects and in most cases a result of surveys including several groups of vegetation. Most of these studies involve description of, for example, the fruit properties for populations in South Africa, Botswana, Namibia (Teichman, 1983; Arnold *et al.,* 1985; Wynberg *et al.,* 2002; Leakey *et al.,* 2005; Viljoen *et al.,* 2008;), Kenya (Thiong'o *et al.,* 2002), Nigeria (Eromosele, *et al.,* 1991), and Senegal (Houerou, 1980); population structure in South Africa (Shackleton, 2002; DFID, 2003), Namibia (DFID, 2003; Ngiitolwa & Hall, 2003), Mozambique (Bandeira *et al.,* 1999) and Zambia (Lewis, 1987); use and/or trade in South Africa (Shackleton *et al.,* 2002; Hall *et al.,* 2002; DFID, 2003), Namibia (DFID, 2003), Ethiopia (AFREA, undated), Sudan (AFREA, undated), Kenya (Beentje, 1994), marula beer properties in Tanzania (Tiisekwa *et al.,* 1996); domestication and/or propagation in Zimbabwe (Karin & Nontokozo, 2006), Malawi and Tanzania (Leakey & Simons, 1998; Swai *et al.,* 2002; Akinnifesi *et al.,* 2008a); and clonal establishment and its performance in Israel (Hillman *et al.,* 2008). Information about taxonomy, distribution, ecology, biology and habit has been gathered from herbaria specimens, literature and other past records (Hall *et al.,* 2002; Teklehaimanot, 2008; Chirwa & Akinnifesi, 2007; AFREA, undated). There are also studies on genetical variation (Kadu *et al.,* 2006; Mouk *et al.,* 2007) and medicinal properties of various parts of the plant (Ojewele, 2003; Moyo *et al.,* in press).

In Tanzania people in rural areas tend to regard indigenous fruits as food for the poor or children (Rufo, 2002) and rate exotic fruits higher than the indigenous ones probably because of their fame and the high market and consumer preference (Akinnifesi *et al.,* 2008a). Previous research bias and the introduction of exotic species may also have contributed to the underperformance of indigenous species despite the fact that they produce fruits which are equally important and sometimes surpassing the exotic fruits in terms of nutritional value. *Sclerocarya birrea* therefore remains underutilized in Tanzania compared to other areas like South Africa where local and commercial markets are significantly developed (Shackleton *et al.,* 2002; Teklehaimanot, 2008; Akinnifesi *et al.,* 2008a).

Work done in the past decade by ICRAF (now World Agroforestry Centre) on germplasm collection, seed germination trials, provenance screening, processing and marketing of indigenous fruits has given promising results, but wider domestication and conservation is still on a small scale (Swai, 2002; Akinnifesi, 2008). The environmental and socio-economic conditions important for life of people in East Africa have been reported to be deteriorating and unless the situation is checked, life will soon be almost impossible. Domesticating and cultivating fruit trees are among the best ways to improve food security; increase local and foreign cash generation and maintain agricultural systems (Teklehaimanot, 2008). Therefore more research and development effort is needed with the aim of coming up with a strategy for successful domestication and cultivation of the fruit trees. Focus should be on identification and selection of superior varieties, domestication of the best varieties, multiplication and distribution, incorporation into farms, management and marketing of the developed crops (Teklehaimanot, 2008). For Tanzania, *Sclerocarya birrea* is already ranked as the top priority tree.

Understanding local knowledge, population status, regeneration, phenology, silviculture including propagation and physiological requirements, yield estimation, harvesting and postharvest techniques and marketing can contribute in establishing a strategy for development, conservation and domestication of *Sclerocarya birrea* in Tanzania. Carrying out these assessments on the three subspecies at the same time is important not only to understand variations that exist between the subspecies but also to form a basis for the development of domestication interventions in different parts of the country. This study also gives information important in bridging the knowledge gap existing between subspecies *multifoliolata* and the other two subspecies.

Population assessments need to be conducted to give the status of the *Sclerocarya birrea* resource available, its distribution, characteristics of various populations and changes occurring in them. These in turn provide a picture of the future prospects of the *Sclerocarya birrea* resource and how it can be managed in a sustainable way (Hett and Louks, 1976; Bawa & Krugman, 1991; Ndangalasia *et al.,* 2007). It also helps in deciding resources or products to be harnessed and forecasting yield over time. Population status of a species is determined based on assessment of the population structure in terms of size class distribution of the species. Knowledge on the structure of the population is of considerable importance in management of any species or forests in general. Tree size-class distributions are widely used to understand and predict sustainability of forests and to indicate whether a species is increasing or declining in abundance (Rubin *et al.,* 2006; Ndangalasia *et al.,* 2007).

Understanding traditional local knowledge surrounding use and management of forest resources is also important. Despite the rich ethnobotanical knowledge accumulated over centuries within societies, the knowledge which is mostly dynamic; remains oral and mostly held with the elderly people in local communities. Documentation on uses and management of *Sclerocarya birrea* by communities across its range is available (Shackleton, 2002; Hall *et al.,* 2002, DFID, 2003; AFREA, undated), however literature shows that perceived knowledge varies from place to place. Also in many ways past and current indigenous knowledge on *Sclerocarya birrea* (like many other indigenous fruits), and their uses in Tanzania, is largely inadequate and scattered among various sources. In particular, the attention given to research on the useful wild plants and the indigenous knowledge associated with them is limited. Successful wise-use of *Sclerocarya birrea* will be more difficult without taking aboard the knowledge held within traditional societies.

Understanding phenophases of a species is also important. The timing at which seeds and vegetative material can be collected for propagation is highly influenced by the phenology of a species (Hartmann & Kester, 1997). Success of vegetative propagation in many plants is well known to be correlated with periods of flowering and/or resumption of active growth (Joshi *et al.,* 1991). The timing of flowering between males and females and their spatial distribution need to be understood as these may have a strong influence on the overall pollination and seed production (Cruden *et al.,* 1976;

Rubin *et al.,* 2006). Baseline information on yield estimates and fruit properties is also important for species intended for domestic consumption and commercialization like *Sclerocarya birrea.*

The most desirable means by which the management, conservation and utilization of *Sclerocarya birrea* can be improved is through domestication. Domestication of *Sclerocarya birrea* has been shown to require cheap material inputs and labor, (Swai, 2002; Teklehaimanot, 2008; Akinnifesi *et al.,* 2008), and therefore its domestication stands a very good chance of being accepted by farmers. Another reason for expecting success in domestication is the fact that benefits from the species are many and are already known to a good mix and number of stakeholders (Shackleton, 2002; DFID, 2003). Domestication can be approached through two strategies i.e. implemented on farm by farmers for low input farming or through genetic improvements on research stations for intensive and high commercial value farming (Leakey & Akinnifesi, 2008). These two strategies are an evolution within the agroforestry system where market-driven objectives are now important than before (Simons & Leakey, 2004; Leakey & Akinnifesi, 2008).

Domestication is a useful tool for *ex-situ, in-situ and circa-situ* conservation because it contributes to wise use of genetic material outside or inside the natural environment and through cultivation (Leakey & Akinnifesi, 2008). Domestication reduces dependency pressure on natural reservoirs or populations where the species can be safely conserved (Simons, 1996; Dawson, 1997; Leakey & Akinnifesi, 2008). Domestication is also important in ensuring supply and uniformity of quality which are very important in today's market, and there is more interest in using vegetative propagation approaches because of this. Several biological and economic factors have been identified that favour clonal approach rather than the traditional seed-based foresters' domestication approach (Leakey & Simons, 2000; Akinnifesi *et al.,* 2006). Domestication is important since recovery through natural regeneration within forests is minimal (AFREA, undated). However information on appropriate propagation approaches for *Sclerocarya birrea* is scant to none and is sometimes inconsistent (Oronu *et al.*, 1998; Herbert *et al.*, 1998 and Swai 2001). Various literature suggests that *Sclerocarya birrea* can be propagated by seed, cuttings, air layering and grafting. Some authors report that seeds germinate easily while others say careful treatment is needed. Some report the need for scarification of seeds with sulphuric acid to improve germination while others report it is ineffective and also others contradict on levels of success using grafts and cuttings (Teichman *et al.,* 1986; Mbuya *et al.,* 1994; Msanga, 1998; Rufo, 2002; Hall *et al.,* 2002; AFREA, undated).

Vegetative propagation study in the Zambezian region was initiated by ICRAF (Swai, 2002) in order to determine suitable alternative propagation techniques for indigenous fruit tree species. The techniques tested included using stem cuttings and root cuttings and grafting using tip or cleft method. Species tested were *P. curatellifolia, S. cocculoides, V. mombassae, S. birrea, Syzygium guineense, M. indica* and *P. edulis*. In these studies, grafting success was higher than 50% in *Syzygium guineense, M. indica* and *P. edulis*, however *S. cocculoides* and *S. birrea* did not respond to any of the two techniques. Establishment of an appropriate propagation method is therefore needed in order to come up with the best option for farmers to domesticate the species.

The present study was carried out to investigate and develop methods of improving the management and utilisation of the three subspecies of *Sclerocarya birrea*. The ultimate aim was to diversify the income and sustain the livelihoods of local communities. Research from drylands of Africa reveals that rural people are incredibly resourceful, often in the face of extreme hardship. These people don't need to be lectured, pressured or motivated, what they do need however is to be offered choices of, and access to, technologies, practices and information in an environment that makes their efforts worthwhile (CIFOR, 2003). This study provides the foundation for delegating tree management from state departments and other large external organizations to local people.

1.2 Objectives

In order to contribute to the reduction of the gap in knowledge required to successfully harness the potentials of *Sclerocarya birrea* through involvement of farmers in improved management and utilization of the species, the following objectives were developed:

- To assemble the existing literature on *Sclerocarya birrea* in terms of traditional knowledge, population structure, biology, propagation, processing and marketing.
- To simultaneously attain, through original field work representing each of the three subspecies, the following specific objectives: 1. Assessment of traditional knowledge held by communities in relation to the management of *Sclerocarya birrea*, 2. Assessment and comparison of the three subspecies in terms of the respective populations, fruit production and phenology, 3.Development of a cost effective propagation technique for *Sclerocarya birrea* applicable to farmers' environment

To enable fulfill the above objectives several research questions and hypotheses were developed and are presented from chapter III to VI, but generally they center around the following hypotheses:

- Farmers neither understand nor use a wide range of products from *Sclerocarya birrea* and are unaware of management and economic potentials and barriers related to the tree;
- Farmers do not have criteria for plus tree selection applicable to *Sclerocarya birrea*;
- Vegetative propagation approaches and methods for *Sclerocarya birrea* are neither applicable nor affordable under normal rural conditions
- The phenology of *Sclerocarya birrea* do not vary with subspecies, sex, environment and annual weather variations;
- The population structure of *Sclerocarya birrea* in terms of density, size and sex do not differ between the subspecies and populations both in the farm and wild environment.

1.3 Study sites

Three sites from 3 different districts namely Holili in Rombo district, Kiegea in Morogoro district and Malinzanga in Iringa district were selected for this study (fig. 1.1). The sites are at least 400 km apart and at most 1100km far from each other by road. The sites were selected in such a way that each covered one of the three subspecies of *Sclerocarya birrea*. Subspecies *birrea* was found in the northern part of the country (Holili); *Caffra* in the east-central region of the country (Kiegea) and *Multifoliolata* in the southern region of the country (Malinzanga).

- ***Holili***

Holili is an area in Rombo district, close to the famous Mount Kilimanjaro. The Region, Kilimanjaro in which Rombo district and therefore Holili village is located, lies south of the Equator between latitudes 2° 25'S and 4° 15'S South of Equator. Longitudinally the region is between 36° 25' 30" and 38° 10' 45" east of Greenwich. Rombo district and Holili village has a common border with Kenya to the north east part of Tanzania. The district covers a total land area of 1442 km^2 with 57 villages.

In this area the year can be divided into four periods with respect to the amount of rainfall: There are two rainy seasons - a major one in April - May and a minor one in October - December, and two dry seasons, a minor one in January - February and a major one in June - September. There is marked variation in the amount of rainfall according to altitude and the direction of the slope in the mountainous areas. The mean annual rainfall varies from 500 mm in the lowlands to over 2,000mm in the mountainous areas (over 1,600 meters above sea level). Temperatures are closely related to altitude. During the rains, extra cloud cover and evaporative cooling tend to reduce maximum temperatures. Cloud cover also tends to raise minimum temperatures. The hot season lasts from October - March with high humidity; temperatures going up as far as >40 °C in the lowlands. In the mountainous areas temperature ranges from about 15° – 30 °C. The soils of the area vary; there are alluvial soils which are potentially agricultural through irrigation farming due to unreliability of rainfall in those areas. For Holili village the best estimates of weather are as follows. Mean monthly precipitation of 37.92 mm ranging from 0 mm to 170 mm. Mean potential evapotranspiration is 133.60 mm but can range from 105 mm to 170 mm per month. Mean temperature is 21.27 °C and can go as down as 10.21 °C and as high as 43.70 °C. The driest months are January, June, July and August. Wind speed range from 2.52 km h^{-1} to 11.16 km h^{-1}.

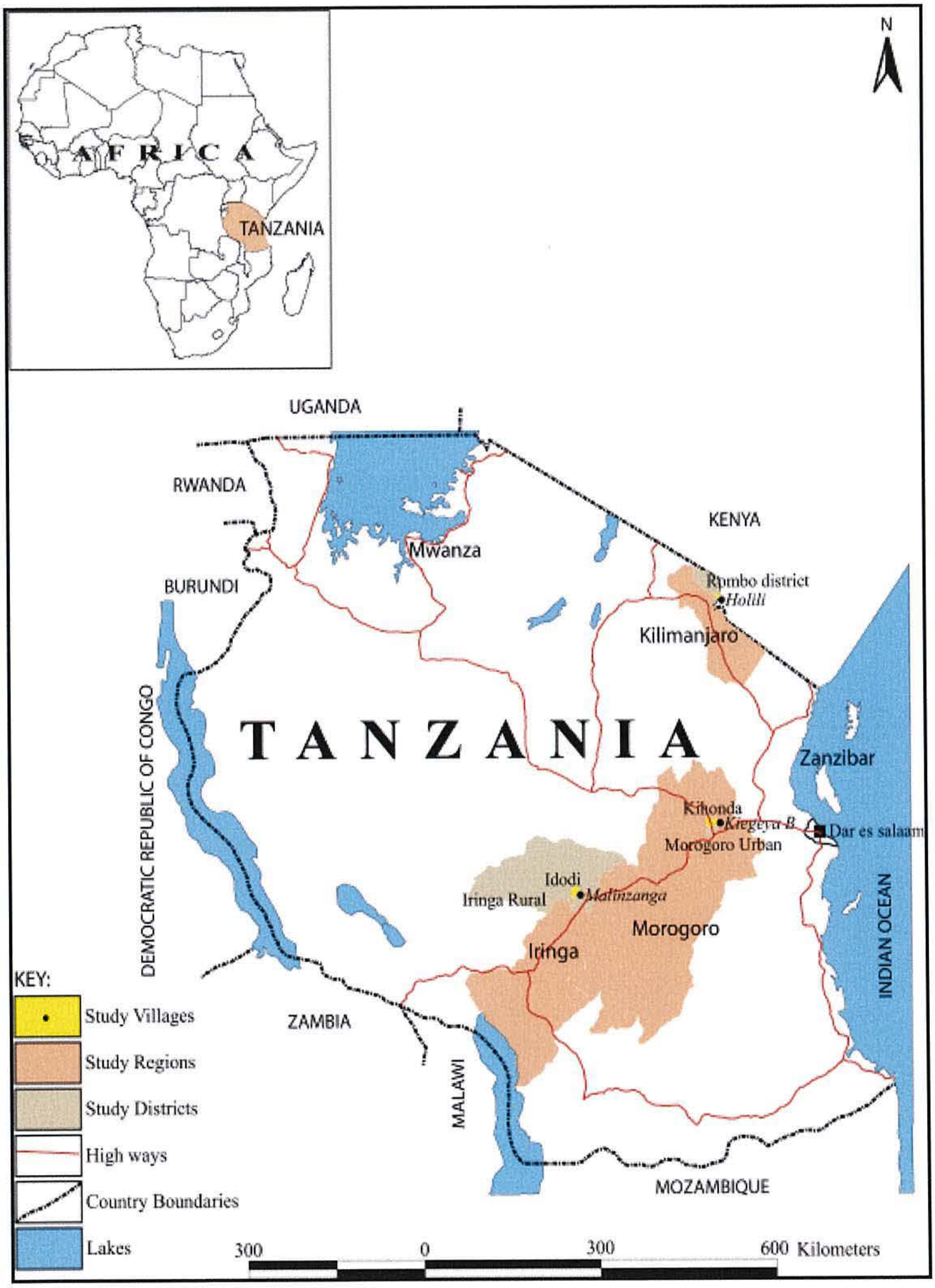
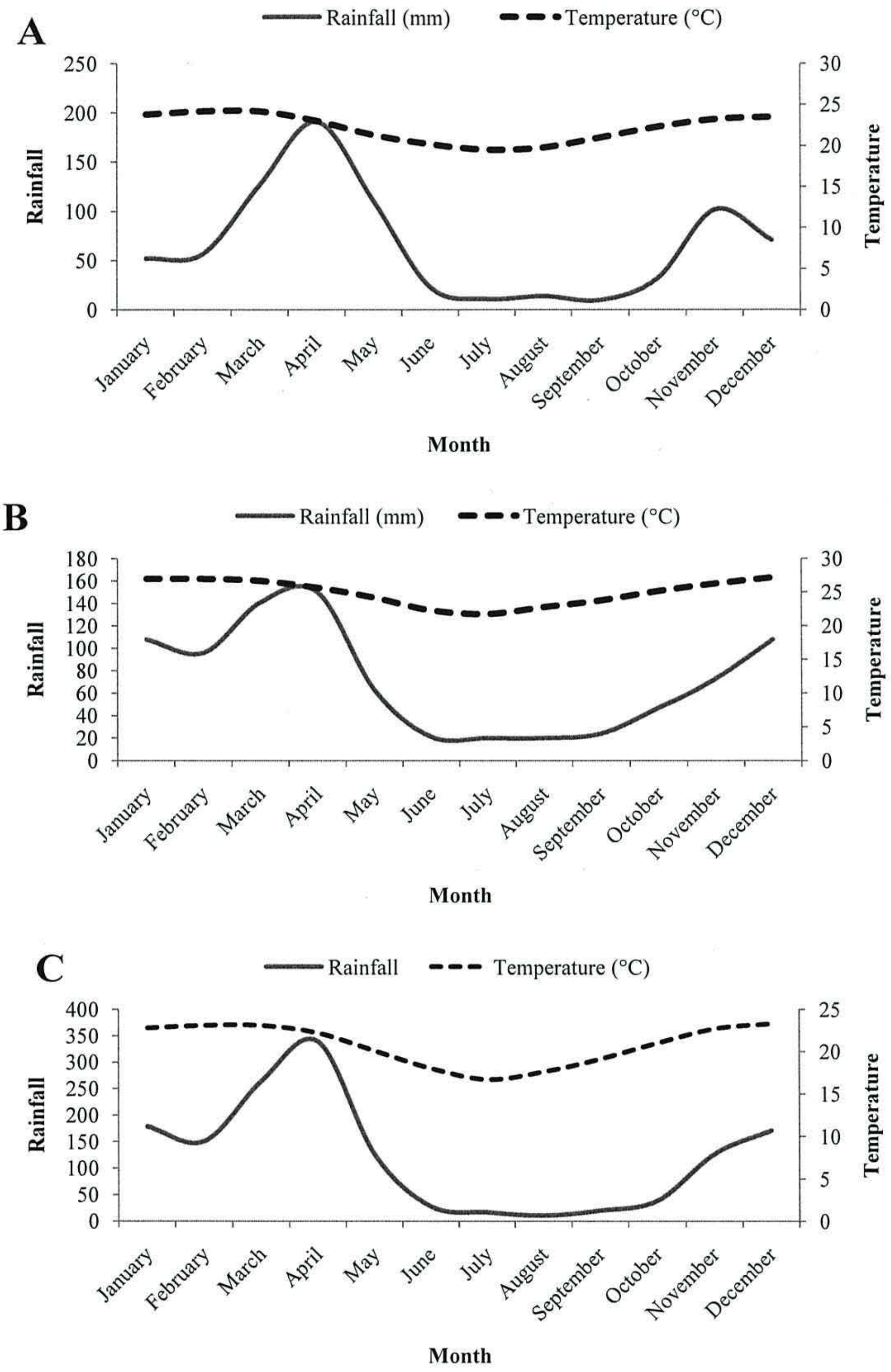


Figure 1.1: Map of Tanzania showing the three study sites: Holili, Kiegea and Malinzanga villages.



01.2: Local climate for the study sites (A – Holili; B – Kiegea & C – Malinzanga). (Source: FAO New_LocClim Data)

- ***Malinzanga***

Malinzanga is located in Iringa region in the Southern highland zone of Tanzania and lies between latitudes 7° and 8° South of the Equator, and longitudes 35° and 36° East of Greenwich. There are six administrative districts: Iringa urban, Iringa rural (now Kilolo), Mufindi, Njombe, Ludewa and Makete. The region lies between 1340 and 1990 m above sea level, has a correspondingly cool climate and agriculture, forestry and livestock production are the main industry. The average annual rainfall ranges between 600 and 1600 mm. By 2002 the region had a population of 1,490,892 people.

Mean precipitation is 54.58 mm per month ranging from 0 mm to 200 mm per month. Potential evapotranspiration is 116 mm but ranges from 77 mm to 180 mm per month. Mean temperature is 23.43 °C, ranging from 8 °C to 30 °C. The driest months are late May to September. Minimum average wind speed is 1.24 km h^{-1} and maximum wind speed is 10.76 km h^{-1}.

- ***Kiegea***

Kiegea is a village located approximately 20 kilometers north south of Morogoro town. Morogoro lies between latitude 5° 58" and 10° 0" to the South of the Equator and longitude 35° 25" and 35° 30" to the East. It occupies a total of 72,939 square kilometers which is approximately 8.2% of the total area of Tanzania mainland and the population is 1,753,362. It is the third largest region in the country after Arusha and Tabora Regions. The annual rainfall ranges from 600mm in low lands to 1200mm in the highland plateau. Mean monthly precipitation is 82.92 mm; ranging from 0 mm to 240 mm per month. The driest months are June, July and August while April receives the heaviest rainfall. Potential evapotranspiration is 112 mm but ranges from 71 mm to 163 mm per month. However, there are areas which experience exceptional droughts with less than 600mm of rainfall. The mean annual temperatures vary with altitude from the valley bottoms to the mountain tops. The average monthly temperature varies between 17.48°C on the mountains to 31.31°C in river valleys. In most parts of the region, the average temperatures are almost uniform at 25°C. In general the hot season runs from July to September. Winds become still (0.00 km h^{-1}) to 11.95 km h^{-1}. The main economic activity is agriculture and the allied activities.

1.4 Organization of the Thesis

This thesis has 7 chapters. Chapter I is the introductory part presenting a background for the study and objectives. Information on the study sites is also presented here. Chapter II covers literature review which describes the state of knowledge on *Sclerocarya birrea* in the following areas: significance, a taxonomic history of morphological description, genetic variation, medicinal/pharmaceutical properties, distribution and ecological requirements, phenology and reproductive biology, propagation and cultivation, uses and nutritional value. Chapter III consists of four sections: Background on uses, market, local constraints and opportunities; material and methods for assessing the local knowledge, results and discussion. Chapter IV is on population status with sections on basic soil properties, population structure, density, size class and sex distribution with graph on frequency *vs* diameter at breast height (dbh); bole height; total height; crown diameter and analysis of variation and regression within and between sites and sex, the status of regeneration, associated species. Chapter V is on phenology and fruit production with sections on leafing, flowering, fruiting, fruit count & fruit properties. Chapter VI details a propagation experiment on *Sclerocarya birrea* using cuttings; air layering and grafting. Chapter VII provides and overall synthesis, general discussion and draws final conclusions.

CHAPTER TWO: EXISTING KNOWLEDGE ABOUT THE THREE SUBSPECIES OF *SCLEROCARYA BIRREA*

2.1. Significance of *Sclerocarya birrea*

Sclerocarya birrea was among five top priority species for domestication in East Africa, ranking first in Tanzania and third in Sudan (Teklehaimanot, 2005) and 'the big five' fruit trees in Africa (Jama *et al.,* 2008). The significance of *Sclerocarya birrea* within societies where the tree occur, especially in terms of social, cultural, food and medicinal uses is suggested to be linked to its attributes notably prolific yields, dioecy and widespread occurrence (Shackleton *et al.,* 2002). Preservation and growth of cultural and traditional knowledge related to the subspecies has been observed from communities where the tree is found. In several countries in the southern part of Africa vocabulary, calendar, dioecy, ethnobotany and organized usage is extensively associated with the species (Shackleton *et al.,* 2002). The value of the tree throughout its range has triggered a norm of preservation by local people through generations resulting into a population with many huge trees of up to >100 cm in diameter at breast height (Nghitoolwa *et al.,* 2003), most of which are females indicating the importance of fruits.

Due to its widespread and availability status throughout the semi-arid deciduous savannas of much of sub-Saharan Africa, the species has emerged as an exceptionally important tree to the society (Shackleton *et al.* 2002, Teklehaimanot, 2005). Its availability and the large size attributes make it a preferred venue for ceremonial events as well as village meeting. As a result the tree receives strong sacred status in societies and therefore strong protection from destructive harvesting especially clear-felling. Because of its wide geographical range, high fruit production potential and many other uses of *Sclerocarya birrea*, it has frequently been identified as a key species to support the development of rural enterprises based on the fruit, beer, or nuts and therefore as a species for potential domestication (Taylor and Moss, 1983; Holtzhausen *et al.,* 1990; Nerd and Mizrahi, 1993; Leakey and Simons, 1998, Leakey & Tomich, 1999, Teklehaimanot, 2005). Indeed, there are few wild species that demonstrate such a wide range of uses or such a significant position in local culture. *Sclerocarya birrea* trees and products have formed an integral part of the lives, food security and spirituality of indigenous communities living within the distribution of this highly valued and versatile species (Krige 1937; Quin, 1959; Fox and Norwood, 1983; SIDA 1992; Shackleton *et al.,* 2000).

Marula beer is brewed by a majority of households and has been shown to be an important key in building and maintaining social networks. It is commonly used for work parties or as a "thank you" for services rendered or anticipated (Gumbo *et al.* 1990, Shackleton *et al.,* 1995, Kadzere 2000). Men, in particular, argue strongly that the sharing of marula beer with friends and neighbours helps to cement reciprocal relations and obligations. The fruiting season coincides with the time of the year when migrant workers retreat to their original village-land for holiday making. In this process they invite each other in their respective homes where marula is a common unifying beer which they drink while cherishing their moments, coming together again and when they leave back to their work they will remember each other with plans and promises to meet again the coming year. It is through these marula ceremonies, where original ties with their homeland are firmly held (Shackleton *et al.* 1995). In Namibia women in neighborhoods gather under large fruiting trees making and drinking beer made from the tree after long tiresome day from fields and homes, giving them an opportunity to relax, gossip, socialize, getting together and strengthening their social capital (Shackleton *et al.,* 2002).

Nutritionally marula fruits are rich in vitamin C, about five times higher than that of the citrus fruit (Leakey, 1999, Teklehaimanot, 2008). At 96% dry matter; the kernel is 57.3% fat, 28.3% protein, 6% total carbohydrates, 2.9% fibre, and rich in phosphorus, magnesium and potassium (Glew *et al.,* 2004). These values become even important because the tree fruit during famine seasons and therefore provide communities with the best option to supplement their food requirements.

The biochemical properties of the fruits, leaves and bark are also important in the cosmetic, pharmaceutical, juice, jam and jellies industry (Kokwaro, 1976; Leakey, 1999; Shackleton *et al.,* 2002; Kleiman *et al.,* 2008; Hillman *et al.,* 2008; Moyo *et al.,* 2010). Fresh marula juice made from *Sclerocarya caffra* genotypes introduced in Israeli are reported to have four times more antioxidant properties than the juice of either orange or pomegranate (Hillman *et al.,* 2008). It has been proved that the bark and leaves from young stems of subspecies *caffra* provide a substantial source of secondary metabolites, which act as natural antioxidants and acetylcholinesterase inhibitors, and may contribute beneficially to the health of consumers much better than synthetic metabolites (Moyo *et al.,* 2010). Also for the first time the mechanism by which *Sclerocarya birrea* is effective in diabetes control has been revealed (Ndifossap *et al.,* 2010). Before this, Dieye *et al.* (2008) reported *Sclerocarya birrea* to be the second most preferred traditional source of diabetes treatment after *Moringa oleifera* in Senegal. Other reports on medicinal values of *Sclerocarya birrea* are given by Mshana *et al.* (2000); Eloff (2001); Hall *et al.* (2002); Ojewole (2003); Dimo *et al.* (2007); Gondwe *et al.* (2008). Todorov & Dicks (2009) have extracted bacteriocin from *Sclerocarya birrea* subspecies *cafra* fruit. Bacteriocins are important in the antibiotic industry. Therefore the species boost a strong significance in the biochemical industry. Most of the recent development in the biochemical industry is being built over the traditional knowledge foundation and documentation of such knowledge held with respect to all the subspecies creates more opportunities for development in the industry.

Information from various literatures suggests that trade on fruit products processed at the household or local setting is more profitable than selling of fruits and/or nuts to processing firms or traders. Studies conducted in some provinces in Namibia and South Africa revealed that households develop beer from marula juice and sell it locally. In some villages dealers earn up to £400 per month through sales of marula beer (Shackleton *et al.,* 2002). Nuts extracted from kernel are sold for about £1.3/kg although the work involves up to 8 man-hours to produce a kilogram. People also sell raw fruits to few large companies involved in production of marula products although at a significantly lower price of £ 0.001 per kilogram (Note: in Tanzania and many sub-Sahara countries the minimum wage is around £ 2.00 per day). Companies do not reliably collect fruits on agreed dates causing fruits to overripe and eventually unsuitable for sale, hence wasting farmer's energy, time and fruits as they are forced to go back into the forest to recollect. Therefore, it appears that, local or household trade of marula fruits and its associated products is more profitable and after all more practical and easy to adopt in other areas where actually purchasing companies are missing. Although the income generated from the trade looks small, for rural areas it help a big deal in paying school fees, uniforms and books as well as buying necessities for household consumption (McHardy, 2003; Shackleton *et al.,* 2005, Leakey *et al.,* 2005). It is therefore a promising income diversification alternative with potentials to replicate in areas where the tree is available but unused for some reasons. In Tanzania where all the three subspecies occur, the significance of the traditional marula beer and other locally traded products has never been assessed.

Sclerocarya birrea is an integral part of agricultural systems across its range, not only because it provides edible fruits and income from sale of its products but also because it contribute to maintenance of the ecosystem functions (Teklehaimanot, 2008). Ecologically Marula is considered a keystone species. This is because of its stature and dominant availability, supporting other forms of life throughout its range. Animal species such as elephants, bees and insect caterpillars use the tree as a host to obtain food or cover. Wildlife and livestock also benefit from the tree due to its several month and adequate availability of shade, fruits and leaves. Under fruiting trees it is evident to find earthworms, beetles, millipedes and other decomposer organisms although ecological studies to examine these magnificent association is lacking (Shackleton *et al.* 2002).

Significance of species can be indicated by, among other things, local priorities and needs of farmers. *Sclerocarya birrea* is spread almost all over sub Sahara Africa where ethnic diversity is very high. The available information on cultural, ecological, economical and social significance associated with *Sclerocarya birrea* is based largely on subspecies *caffra* and *birrea*. Since all the subspecies occur only in Tanzania, there is a chance to understand whether subspecies *multifoliolata* holds unreported usefulness; while at the same time comparing and relating its significance with those of subspecies *birrea* and *caffra* in the same environment.

2.2. A taxonomic history of *Sclerocarya birrea*

Sclerocarya birrea is a member of the Anacardiaceae, along with 650 species and 70 genera of mainly tropical or subtropical evergreen or deciduous trees, shrubs and woody vines (Pretorius *et al.,* 1985). In the past, the Anacardiaceae has usually been divided into four tribes: Anacardieae, Spondiadeae, Rhoeae, Semecarpeae and, sometimes, Dobineae. Recent phylogenetic studies have, however, prompted review of the relationships within and involving the family (Gadek *et al.,* 1996; Terrazas & Chase, 1996; Pell & Urbatsch, 2000, Hall *et al.,* 2002). At family level, it has been suggested by Judd *et al.* (1999) that separation from the Burseraceae makes the Anacardiaceae paraphyletic, with Burseraceae as a sister group (Gadek *et al.,* 1996).

Within the Spondiadeae tribe (18 genera); *Sclerocarya* is one of the seven *Spondias* occurring in Africa (Mabberley, 1997). *Spondias* is found in Africa probably through introduction (Trochain, 1940; Aubreville, 1950). *Lannea* which is another genus in the same tribe has strong links towards the east with one species being found in south Asia. The genus is also closely related to *Operculicarya* and *Poupartia* which are found in Madagascar and other Indian Ocean Islands. Of its seven genera found in Africa, *Sclerocarya* and *Lannea* are the most widely distributed, with the later being the most diverse with 40 recognised species and found in dryland habitats, same as *Sclerocarya* (Hall *et al.;* 2002). Shackleton *et al.* (2003) reports four species of *Sclerocarya* according to Mabberley (1993), which include *Sclerocarya birrea* and *Sclerocarya gillettii*. The remaining two are not mentioned. But according to Hall *et al.* (2002) *Sclerocarya* has two species which are *Sclerocarya birrea* and *Sclerocarya gillettii* which is a Kenyan endemic with a much narrower distribution.

The origin of *Sclerocarya birrea* has been thoroughly reviewed by Hall *et al.* (2000) based on assessments of past fossil records, botanical collections and corresponding environmental changes over geographical time scale. They point out that absence of *Sclerocarya* from other tropical regions suggests that its origin remain African. Its poor adaptation to long distance dispersal across water means that the Madagascar population is a result of introduction because Madagascar separated from the main African landmass long before the appearance of *Sclerocarya* or other *Spondias*. The distribution pattern of *Sclerocarya* suggests it originated from the Southern part of the continent and spread northwards to the savannas by Mammalian dispersal agents (Bigalke, 1978). The exact origin is unclear but it is a possible deviation from a forest ancestor of a species able to occupy relatively more extensive dry conditions. Intense patterns of climate, drainage and soil variations caused by environmental heterogeneity later on establishing a corridor of aridity which separates the north and south savannas suggest relationship with the presence of subspecies *birrea* in the north and subspecies *caffra* in the south. *Sclerocarya gillettii* is restricted within the arid corridor suggesting that the environmental changes caused its differentiation from *Sclerocarya birrea.*

The history of *Sclerocarya birrea* begins where the first botanical record of the species was made by Perrittet about one and a half century ago in Senegal. Initially the species was associated with the genus *Spondias* at least up until in the 1920s (Hall *et al.,* 2002). Separation from Spondias was made based on floral differences, particularly the higher numbers of stamens in *Sclerocarya.* In the 1850s another plant relating with the West African *Sclerocarya* but with different leaflet morphology was identified in South Africa and was described as a second species under the genus *Sclerocarya.* A specimen matching the South African *Sclerocarya* collected from Mauritius in the 1840s was described as a third species in 1877. This lasted for a short while because in 1883 it was concluded that the Mauritius and South African species were the same, so the genus was reduced to two species namely *Sclerocarya birrea* (from West Africa) and *Sclerocarya caffra* from South Africa and Mauritius. In the late 1880s another species from Namibia was described as *Sclerocarya schweibfurthiana.* This Namibian *Sclerocarya* survived for almost 80 years before being described to be similar to *Sclerocarya caffra* in 1968. Consideration of *Sclerocarya birrea* and *Sclerocarya caffra* as separate species ended in 1980 when Kokwaro and Gillett reduced them into the rank of subspecies while revising the taxonomy of Anarcadiaceae. In the same period Engler described a third subspecies, *Sclerocarya multifoliolata,* using specimens collected from Tanzania in the late 1880s while at the same time describing a new species *Sclerocarya gillettii* (Hall *et al.,* 2002).

There are still active debates on taxonomic circumscription for *Sclerocarya* but the latest by Kokwaro & Gillet (1980); described by Hall *et al.* (2002) is widely used. Hall *et al.* (2002) describes that Friedmann (1997) and Schaltz (2001) recognise *Sclerocarya* as *Porputia* and that the recognition was also held by Marchand (1869), Bathie (1944) and Aubreville (1950). Despite the name *Sclerocarya* being retained in the flora of West Tropical Africa by Ronald Keay (Hutchison & Dalziel, 1954-1958) and flora of Tropical East Africa by Kokwaro (1986); Hall *et al.* (2002) reported that, the two authors still treat the view of *Porputia* with some respect. The distinguishing features which have been used to separate *Sclerocarya* from *Porputia* are the number of reproductive parts of the flowers and number of flowers per female inflorescence. Randrianasolo (2001) as noted by Hall *et al.* (2002) reports that *Porputia* has 8-10 stamens and 5 stigmas while *Sclerocarya* has 12-26 stamens and 2-3 stigmas. Also it has been claimed that the females of *Porputia* have many flowers compared to the female inflorescence of *Sclerocarya* which have 1-3 flowers with sessile or smaller peduncles.

2.3. The three subspecies of *Sclerocarya birrea*

Sclerocarya birrea has three subspecies across its range, Tanzania being the only country where all of them can be found, although Mouk *et al.* (2007) proposes further taxonomic work to assess the possibility of the occurrence of subspecies *multifoliolata* in Nyanza region, Kenya.

The three subspecies can be differentiated based on foliar and inflorescence morphology. Subspecies *cafra* is characterized by having the fewest number of pairs of leaflets (3-6), followed by *birrea* with 7-10 pairs of leaflets; and *multifoliolata* has the largest number of leaflets (12-18 pairs) which are the smallest in size (Plate 2.1c & d). The leaf lamina shape of *multifoliolata* is round or broadly elliptic differentiating it from *birrea* which is elliptic-obovate and *caffra* which is oblong-ovate at the leaflet base. In general subspecies *birrea* and *caffra* have a more elongated leaflet shape when compared with subspecies *multifoliolata.* Subspecies *caffra* have 0.5-3.0 cm long petiolules for the lower pair of leaflets, an acuminate or cuspidate leaflet apices and the frequently long (up to 22 cm) inflorescences of male plants. Both subspecies *birrea* and *multifoliolata* have sub-sessile or very shortly petiolulate lower or terminal leaflets, blunter leaflet apices and male inflorecences with a maximum length of 9 cm (Hall *et al.,* 2002).

Subspecies *caffra* is the most omnipresent occurring in east tropical Africa (Kenya, Tanzania), south tropical Africa (Angola, Malawi, Mozambique, Zambia and Zimbabwe) and southern Africa (Botswana, Namibia, South Africa and Swaziland) and is also recorded from Madagascar (Arnold and de Wet, 1993; Hall *et al.,* 2002; Mouk *et al.,* 2007). The southern end of its range is the coastal belt of southern KwaZulu-Natal, South Africa near Port Shepstone at approximately 31^0 S. Subspecies *multifoliolata* has the narrowest range and occurs in mixed deciduous woodland and wooded grassland in Tanzania. The subspecies *birrea* occurs through west, north-east and east tropical Africa across a range of vegetation types, principally mixed deciduous woodland, wooded grassland and through the open dry savannas of Northern Tropical Africa and the Sahelian region (Shackleton *et al,* 2003).

As noted earlier, for some reasons, the Tanzanian populations remain less studied and therefore the available information on *Sclerocarya* comes out of work done on subspecies *caffra* and *birrea.* An assessment of genetic variation using some populations from Tanzania as reference discovered that there is a remarkably distant gene relationship between geographically proximate populations more than anywhere else across the southern region (Kadu *et al.,* 2006). It appears, therefore, that a large portion of the genetic variation present in *Sclerocarya birrea* in the entire southern Africa region is represented in Tanzania, presenting particular opportunities nationally for evaluation, conservation and cultivation of the species. Such genetic variation might be reflected in the population structure, phenophases of the populations as well as fruit production and properties. Populations with high levels of genetic variation are valuable since they offer diverse gene pool from which gene conservation and improvement programs can be made (Mouk *et al.,* 2007). Therefore the Tanzanian population gives a unique opportunity to simultaneously study and compare the three subspecies while at the same time adding to the existing literature, on subspecies *birrea* and *caffra,* information about *multifoliolata.*

2.4. Morphological description of *Sclerocarya birrea*

The marula is typical of the family Anacardiaceae in several ways, including resin ducts in the bark, dioecy and the production of fleshy fruits by female trees. Although *Sclerocarya birrea* is usually considered a dioecious species, occasional trees with male flowers may bear a few female flowers. For example, Teichmann (1982) found that out of a random sample of 119 trees, 104 (87.4%) were dioecious, with the remaining 15 (12.3%) being predominantly male flowered with a few female flowers on the lowermost 1 - 2 inflorescences.

Like *Sclerocarya gillettii* (Beentje, 1994) and some well-known crop plants in the Anacardiaceae, such as the mango (*Mangifera indica*) and mombin (*Spondias*), marula fruit pulp is edible. In addition, like fellow Anacardiaceae, such as the cashew (*Anacardium occidentale*) and pistachio (*Pistacia vera*), *Sclerocarya birrea* produces edible nuts although there are no published reports of people consuming nuts from subspecies *multifoliolata*.

The marula tree is a medium-sized dioecious, single stemmed tree with an average height of 10 m but ranging from 5 – 17 m in height (Kokwaro, 1986, Coates-Palgrave, 1988; Taylor & Kwerepe, 1995; Mojeremane & Tshwenyane, 2004, Teklehaimanot, 2008). This profusely branched evergreen or semi-deciduous tree has a short trunk and spreading branches that form a dense rounded crown. The stem is generally short but sometimes can have up to a 9 m clear bole. The diameters of mature trees fall within the range of 15 to 25cm with diameters of up to 100 cm being recorded in some places (Nghitoolwa *et al.,* 2003). The stem bears stout and short branches which have prominent leaf scars. The bark is pale to dark grey or grey-brown, thick and deeply fissured or flaking in patches exposing the underlying light yellow to red tissue in mature individuals (Eggeling & Dale, 1951; Ghazanfar, 1989; von Maydell, 1990; Van Wyk & Van Wyk, 1997; Palgrave, 1988; Rufo, 2002; Mojeremane & Tshwenyane, 2004, Teklehaimanot, 2008). The bark of young trees is smooth and grey or pinkish grey. The inner bark is red or pink (Plate 2.1a) to yellowish with darker stripes (Kokwaro, 1993; Mojeremane & Tshwenyane, 2004).

The fruit size is variable, but is roughly plum-sized (Leakey *et al.,* 2005; Hillman *et al.,* 2008). Marula fruits abscise before ripening; at this stage the skin colour is green and the fruit is firm but changes colour with days for up to three weeks (Plate 2.1b; Hillman *et al.,* 2008). The ripe fruits have a thick yellow peel and a translucent whitish flesh (Ghazanfar, 1989; von Maydell, 1990; Rufo, 2002). Watt and Breyer-Brandwijk (1962) describe the outer skin as having "a pungent apple-like odour" and marula pulp flavour as a mixture of "litchi, apple, guava and pineapple".

Local people in areas where subspecies *caffra* is found know very well that the fruit size and flavour vary from tree to tree. Fruits types are finely differentiated by local people reflecting the social importance of this species, typifying the folk taxonomy of *Sclerocarya birrea*. The widespread use of similar terminology for description of the species across many southern and south-central African languages shows that the tree's morphology have been studied and known by local people for a long time. Such terminologies or names are normally derived from meanings of some important parts of the plant like fruits or nuts. Examples of this are the names *marula* or *morula* used for the tree in Lovedu, Pedi and Tswana (and the closely related terms *muua* in KiKamba and *mura* in the Meru language in Kenya), *umganu* in siNbebele, Zulu and siSwati and *omwoogo* (or *omyoongo* pl.) in KwaNayama Owambo in Namibia and *muongo* in Gwembe Thonga in the Zambezi valley (with closely related terms in Tanzania, such as *mng'ong'o* in kiSwahili, Digo, Pare and Zaramo) and the related names *mfula* (ChiChewa and Yao) in Malawi and *mpfura* (Shona) in Zimbabwe and *mafula* (Venda) in South Africa (Hall *et al.,* 2002; Shackleton *et al.,* 2005).

Plate 2.1: *a* - Ring-barked marula stem revealing the inner color; *b* - Fruits ripe (on hand); at various stages (on ground); *c* - Subsp. *multifoliolata* leaves; *d* - Subsp. *Caffra* leaves

The root system is a mass of small laterals and deeply penetrating root emerging from the base of the stem. Taproot length varies with tree size, and generally ranges from 50 to 150 cm in length. The dark, shiny green leaves are usually clustered at the ends of the branches, in a spiral phyllotaxy arrangement. They tend to be crowded towards the ends of the branches alternately or in rosettes. They are imparipinnate, 10- 15cm long, and bear 7-15 pairs of opposite leaflets, 2-3 cm long that are very variable in shape (orbicular, ovate, obovate, elliptic) but are always mucronate with the exception of the terminal odd leaflet. They are reddish to brown with short grey to rust coloured hairs beneath when young, turning blue green in colour and glabrescent when older.

Plate 2.2: Reddish brown young leaves

Leaflets from roots suckers, young plants or recently felled stumps are reddish, often serrated, otherwise they are entire (von Maydell, 1990; Mbuya *et al,*. 1994; Rufo, 2002; Jøker & Erdey, 2003; Mojeremane & Tshwenyane, 2004; AFREA, unpublished).

Literature from various sources describing *Sclerocarya birrea* and *Sclerocarya cafra,* as mentioned before, indicates that the species morphological shape, colour and dimension of the floral parts varies slightly. Although the reasons for this are not given, mostly it may be due to normal phenotypic variations between individuals or populations of the species. The tree is dioecious and therefore allogamous. The unisexual inflorescences originate from axillary positions among the leaves or more often below them on the second or third seasons wood of the branchlets. The staminate and pistillate flowers are yellow or greenish reddish in color and globose in shape (Mbuya *et al.,* 1994; Rufo, 2002).

The fruit is an obovoid to subglobose drupe, usually 3-4 cm in diameter when ripe, on a 10-15 mm long pedicel. The outer layer of the exocarp is thin and tough, covered with small rough spots and 2-3 obscure points representing stylar remnants near the apex (Shone, 1979; Teichman, 1982). At maturity the colour is yellow and under the thick (2-3 mm) exocarp is a fibrous, fleshy, juicy mesocarp adherent to the hard stone (endocarp). The endocarp is obovoid, 2-3 cm long and 1.5-2.5 cm in diameter, with 3-4 compartments, each operculate towards the tip with an irregularly elliptic or discoid operculum. Within each compartment is a flattened seed 15-20 mm long, 4-8 mm wide and 2.5 mm thick. The seed is oleaginous and lacks endosperm. It is enclosed in a papery brown testa. The cotyledons are plano-convex, thick and fleshy (Bâthie, 1946 cited by Hall *et al.,* 2002).

2.5. Distribution and ecological requirements of *Sclerocarya birrea*

A recent *Sclerocarya birrea* distribution map for Africa is given by Hall *et al.,* (2002) but in the past regional (Aubre`ville, 1950; Mullenders, 1954 and Peters, 1988) and national (Urvoy, 1937; Trochain, 1940; Grondard, 1964; Shone, 1979; Palgrave, 1983; Beentje, 1994 and Maundu *et al.,* 1999) level maps have been made.

2.5.1 Distribution

Sclerocarya birrea is frequently a community dominant and hence is a keystone species in plant and animal community ecology and productivity, occurring through most of sub Saharan Africa (Hall *et al.,* 2002) both on the wild and agroforestry parkland environments (Teklehaimanot, 2008). It is found from the Senegal coast (17^{o}02`W) and Mauritania eastwards through Burkina Faso, Nigeria, Mali, Cameroon and Central African Republic to Eritrea and western Ethiopia. In Sudan the range reaches 16$^{o}$42`N at Abu Shendi and 17^{o}15`N in the Åir Maintains of Niger (Fabregues & Lebrum, 1976 and Hall *et al.,* 2002). From Sudan and western Ethiopia the range extends south, through Kenya and Uganda, passing east of Lake Victoria basin, to Tanzania, Mozambique and South Africa and westwards from these countries through Congo, Malawi, Zambia, Zimbabwe, Botswana and Namibia, up to the Atlantic coast in Angola. To the east the species range extends to 50^{o}09` in Madagascar (VanWyk, 1974; Kokwaro and Gillet, 1980; Kokwaro, 1986; Hall *et al.,* 2002; Mojeremane & Tshwenyane, 2004; ICRAF, 2005, Shackleton *et al.,* 2005, Leakey *et al.,* 2005; Akinnifesi *et al.,* 2006).

Its three subspecies occupy different parts of this range but all occur in Tanzania where the southern limit of subspecies *birrea* is in the northern part of the country. Subspecies *caffra* has been reported only south of equator, the range broadly coinciding with that of subspecies *birrea* in northern Tanzania and southern Kenya (Hall *et al.,* 2002). Tanzania is the centre of diversity for the species (Kokwaro and Gillet, 1980; Kadu *et al.,* 2006; Mouk *at al.,* 2007) suggesting a wide gene pool that would be important for the development of improved germplasm.

Records of availability and abundance differ across the species geographic range. Areas noteworthy for low number of records are the extensive flood-prone areas of Southern Chad for subspecies *birrea* and eastern Angola for subspecies *caffra*, although limited botanical exploration (Hepper, 1979) may imply in this information (Hall *et al.,* 2002). Subspecies *birrea* is frequent in Senegal, Burkina Faso, northern Nigeria, Cameroun and Kenya while subspecies *caffra* is frequent throughout Tanzania, Malawi, Zambia southwards to south Africa and the coastal plains of Mozambique and South Africa. Desert conditions limit the range of subspecies *birrea* to the north and its eastern limit in Kenya. Desert conditions in combination with occurance of regular frosts limit the range of subspecies *caffra* to the southwest in Namibia. To the west of Lake Victoria, neither subspecies *birrea* nor *caffra* penetrates the humid Guineo-Congolian region although subspecies *caffra* is well represented to the south, in Katanga, of DRC in the Guineo-Congolian/Zambezian transition zone (Hall *et al.,* 2002). The species is also reported to be introduced in experimental plantations and/or botanical gardens in Israel, Reunion, Mauritius, Comoros, USA, India, Oman and Australia (Hall *et al.,* 2002; Hillman *et al.,* 2008).

In Tanzania, where all the species are available, it may be interesting to understand the local distribution of the subspecies, whether there is a local north-south overlap in occurrence of the subspecies. If they overlap, then understanding the ecology and habitat characteristics associated with the populations may form a basis of understanding why the subspecies don't exist together in other countries. The use of different names, *mbwegele* and *mtondoko* (Hall *et al.,* 2002), by a single tribe (the Matengo from Songea, southern Tanzania) probably indicates that they refer to two different subspecies most likely *caffra* and *multifoliolata.* Similarly the use of same/related names, by different ethnic groups from different regions within Tanzania may be reflecting the understanding of the subspecies belonging to the same genus. The species is called *ng'ongo* by the Sukuma from Western Tanzania, *mng'ong'o* by the Nyamwezi and Nyaturu from central-western Tanzania, *mng'ongo* by Zaramos from eastern Tanzania, *mng'ong'o* by the Pare from north-eastern Tanzania and *olmang'oi* from northern Tanzania (Hall *et al.,* 2002).

2.5.2 Population density, size and sex structure

The bias of research effort in African woodland areas focusing management for commercial timber production, using exotic species of *Pine* and *Eucalyptus* (Chihambakwe, 1987; Harrison, 1987) has affected population studies of most indigenous species. However a growing international concern over impacts of introducing new species in native areas on local biodiversity and spread of pests and diseases (Teklehaimanot, 2008) has increased momentum in shift of interest on indigenous trees. Even though there has been growing interest in indigenous species in the past two to three decades, research has focused on ethnobotany and description of NTFPs in relation to their potential for domestication and commercialization (Shackleton, 1996; Maghembe *et al.,* 1998; Akinnifesi *et al.,* 2004, 2006). Little is known about the population size and structure, genetic variation, growth rates and biomass yield of indigenous trees, and therefore of their suitability to sustained management. Such information would improve the usefulness of estimates of sustainable yields and the possibilities for long term management of these trees. For *Sclerocarya birrea* there is limited to none systematic appraisal of the densities and productive capacity throughout its range. With a few exceptions DFID (2003) – inventory in some provinces in Namibia and South Africa and Gouwakinnou *et al.* (2009) – inventory in Northern Benin; most of the existing data are largely a coincidental result from other work recording densities of all woody species for vegetation mapping or characterisation purposes (Shackleton *et al.,* 2002).

The abundance of *Sclerocarya birrea* subspecies *caffra* from a communal land area called Timbavati in South Africa was reported by Shackleton (1996) to be 7.5 stems per hectare for adult individuals and 41.9 stems per ha including juveniles. This abundance is similar to the 8 stems (> 2 m tall) per hectare reported by Lombard *et al.,* (2000) for Gottenburg communal lands in the same country. In the Lebombo Mountains of Mozambique, Bandeira *et al.,* (1999) reported a density of 37.5 stems per hectare for individuals greater than 1.5 m tall. In terms of tree size Bandeira and his team recorded an average DBH of 17.1 cm. In Luangwa valley (Zambia), Lewis (1987) undertook a population inventory and found a mean density of 14.8 trees per hectare, with a mean height of 7.6m.

Studies in South Africa and Namibia suggest that land use affects population, sex and size structure of *Sclerocarya cafra* (DFID, 2003). Through inventory they found marula density being greatest in the protected areas and least in agricultural fields. However the protected areas were dominated by juveniles because 73% of the populations in the agricultural fields were adults while in the protected areas adults accounted for only 13% of the whole population. This indicates reduced recruitment in the agricultural environment, but a high proportion of potentially big and useful trees. There were more females than male trees in both populations with a slightly more female abundance ratio on agricultural lands. It is suggested that the sex distribution is more a result of many years of selection pressure and domestication objectives retaining females for fruit production and harvesting males for wood products (Leakey et al., 2005).

A stand density of 1.5 trees ha^{-1} (including individuals of 1cm diameter) was found by Nghitoolwa *et al.* (2003) during gender distribution survey for on farm population of subspecies *caffra* in two neighbor villages in Namibia. They encountered trees with DBH up to 100 cm and most of the trees (60%) had a DBH of more than 20 cm. In one of the two villages, the sex ratio of larger trees (40–80 cm DBH) was significantly skewed in favour of females, indicating variation of population attributes even when they are geographically close. For the case of Tanzania where there are different subspecies in an environment with a history of trade routes and occupied by among the most ethnically diverse area in Africa, understanding the size and sex distribution is of interest and may highlight a unique anthropogenic relationship with the species (Kadu *et al.,* 2006). In northern Benin adult density for subspecies *birrea* was a little less than 10x higher in a protected area compared to farmland areas. Germination was found to be more robust but with poor seedling survival on farmlands than inside the forests. Farmland adults had bigger (2x) DBH compared to wild populations (Gouwakinnou *et al.,* 2009). An eight year assessment of mortality responses of subspecies *caffra* to damage by wildlife browsing and fire revealed a rapidly declining population of saplings and adults (Helm *et al.,* 2009). *Sclerocarya birrea* subsp. *caffra* is reported to be the third most dominant species (80%) on rural gardens in Zululand, South Africa; the assessment however included introduced plants (Nemudzudzanyi *et al.,* 2009).

As is for many African indigenous species the available information on *Sclerocarya* about abundance and population structure is from unsurprisingly proportionally few and small areas, although the species geographical range is very big. For appropriate management of plant resources either or both for conservation, commercialisation and improvement of livelihoods of communities living adjacent to forests; species-level and specific habitat and land use types assessments are a necessity which should not be overlooked (Bruna and Kress, 2002; Ndangalasia *et al.*, 2007; Chazdon *et al.*, 2009; Gouwakinnou *et al.*, 2009). The inventory data above covering some areas in Namibia, South Africa, Mozambique and Zambia are for subspecies *caffra* while that from Benin is for subspecies *birrea*. Until now population density and structure for subspecies *multifoliolata* is not given anywhere while a comparison of populations of the three subspecies is also yet to be done. For successful conservation, utilisation and domestication campaigns in Tanzania information on how these populations are distributed and the respective habitat characteristics is important.

2.5.3 Ecological requirements

Sclerocarya birrea can be found in a diversity of vegetation types; typically, open, deciduous savannas, but it is also a component of semi-deciduous forest (Johnson and Johnson, 1993). Few studies have been done on the species habitat condition (Jacobs and Biggs, 2002) but Shackleton *et al.* (2002) warns that majority of the existing information on population studies includes collection of observations, lacking reliable methodologies.

The species is a drough tolerant and lowland dweller found on elevations below 1600 m with a few exception reports of occurrence in altitudes of up to 1800-2000 m. Mean annual rainfall in its range is between 200-1600 mm (Peters, 1988) but typical 400-1500 mm (Hall *et al.*, 2002; Shackleton *et al.*, 2005) with monthly mean of 50 mm in 4-7 months for subspecies *birrea* and 5-7 months for subspecies *caffra*. Subspecies *caffra* occurs in more humid conditions in the south while *birrea* occurs in more arid conditions in the north. Populations north of the equator receives mean annual temperature range of 22-29 °C while those in the south mean annual temperature is 19-26 °C. There are populations which face extreme temperature levels of -4 to 5 °C in southern South Africa and 35-45 °C in Mali (Shone 1979; Peters, 1988; Bandeira *et al.*, 1999; Hall *et al.*, 2002; Mojeremane & Tshwenyane, 2004).

Sclerocarya birrea prefer sandy to loamy soils (Fox & Young, 1982; Mojeremane & Tshwenyane, 2004) with a preference for well-drained soils (Lewis 1987). The most extensive soil types are shallow sandy lithosols, except towards the base of the catena where deeper duplex soils are common (Acocks, 1988). Heavy soils are unsuitable (Timberlake, 1980) although a few exceptions of clayey basaltic soils have been reported to suit the species (Tuley & Alford, 1975; Werger & Coetzee, 1978; Shackleton & Scholes, 2000). The species is reported to demonstrate a wide range of tolerance to soil conditions where it can be found in acidic, neutral and alkaline soils. The most common is pH of 5-7 but extreme acid conditions of pH 4.5 in Sudan (Morison *et al.,* 1948) and more alkaline soils in Tanzania (Vollesen, 1980) have been reported. The species survive in a broad range of soil fertility. It thrives in poor and eroded soils with very low levels of total nitrogen and phosphorus like some areas in Mali to nutrient rich soils like some areas in Tanzania (Hall *et al.,* 2002).

2.5.4 Species associates

The tree is found in mixed deciduous woodland and wooded grassland; in most case reported to be associated with *Lannea* and *Combretum spp.* (Mbuya *et al.,* 1994; van Wyk & van Wyk, 1997; Rufo, 2002; AFREA, unpublished). Inventories have shown that the tree stratum associated with marula trees is dominated by members of the Combretaceae (*Terminalia sericea, Combretum collinum, C. hereroense, C. zeyheri* and *C. apiculatum*) and Mimosaceae (*Acacia nilotica, A. gerrardii, A. ataxacantha, A. caffra, A. sieberana, Albizia harveyi, Albizia versicolor* and *Dichrostachys cinerea*), although local dominance varies considerably (DFID, 2003). The different subspecies are reported to be associated with different vegetation and species types. However since all the subspecies occur in Tanzania possible overlap in occurrence of the associates of *Sclerocarya birrea* is worth investigating.

2.6. Genetic diversity of *Sclerocarya birrea*

Although important for appropriate use and conservation, little information is available on regional and local genetic variation of *Sclerocarya birrea*. Kadu *et al.* (2006) observed a strong positive correlation between Rapid Amplification Polymorphic DNA (RAPD) data and geographic distance for 12 populations of subspecies *caffra* sampled from seven countries. A cluster analysis of the same populations showed variation between proximal stands in samples collected from Tanzania. The Tanzanian populations indicated an exceptionally high diversity as they expressed 3 haplotypes while all populations from the remaining six countries expressed only 2 haplotypes. Through analysis of RAPD and chloroplasts data it was discovered that marula genes easily flow through pollen rather than seeds. Kadu *et al.* (2006) suggests that Tanzania provides particular opportunities for evaluation and conservation of the species, and should be a focus for research and development. The populations in Tanzania also provides the best opportunity for studying human influence on genetic diversity because of the proximity of genetically distinct subspecies and the presence of important historical trade routes along with transfer of germplasm (Misana *et al.,* 1996). In another study phenotype and genotype assessment using six samples from Kenya and two reference populations from Tanzania indicated similarities and variations between all populations. Interestingly they observed a similarity both in phenotype and genotype between Nyanza populations from Kenya and subspecies *multifoliolata* population from Tanzania (Mouk *et al.,* 2007). This suggests that the range of *Sclerocarya birrea* subsp. *multifoliolata* may be wider than once thought, and merits further classification while the wider gene pool in the region present great opportunity for conservation and plant improvement.

Further studies on marula shows that marula genotypes from clones established in Negev desert, Israel produces different amounts and sizes of fruits (Hillman *et al.,* 2010). It is therefore important to put emphasis in understanding variations and identify superior genotypes for marula. Information on the quantity and quality of *Sclerocarya birrea* DNA has just started to emerge. Isolated DNA from subspecies *caffra* has shown good spectral qualities suitable for PCR amplification and can be used for molecular biology applications such as amplified fragment length polymorphism and DNA cloning (Moyo *et al.,* 2009). A relationship between phenotypic and genotypic properties of the species was found in two populations in South Africa (Moganedi *et al.,* 2011).

The information on genetic diversity of *Sclerocarya birrea* populations from Tanzania is a result of studies aimed at subspecies *caffra* and *birrea* in other countries where the Tanzania populations were used for reference (Kadu *et al.,* 2006; Mouk *et al.,* 2007). For successful conservation and domestication of this valuable gene pool resource more research is required to compare the three subspecies as well as to improve knowledge on subspecies *multifoliolata.*

2.7. Phenology and reproductive biology of *Sclerocarya birrea*

2.7.1 Leafing

Studies in *Sclerocarya birrea* show that budding, flushing, leafing, shading and their respective duration is related to amount and duration of rainfall (Hall *et al.,* 2002). Generally budding, flushing and consequently leafing would start at the beginning of rain seasons and shedding starting with the onset of the dry seasons. In areas with two rainfall seasons in a year, shedding normally starts during the onset of the long dry spell (Bie *et al.,* 1998; Munjuga, 2000). However some studies on subspecies *caffra* have reported flushing towards the end of rain season (Hall-Martin & Fuller, 1975; Storrs, 1979, Teichman, 1982; Hall *et al.,* 2002). Monitoring of subspecies *birrea* in Burkina Faso showed that the trees stay leafless for up to 8 months when mean annual rainfall is <600 mm but when more mean annual rainfall 800-900mm is received the leafless period is reduced by up to 3 months. Soils with good moisture retention properties tend to prolong shedding by extending the duration of water availability for the tree even after rains stops falling (Seghieri *et al.,* 1995; Devineau, 1999). Specific information about the phenology of subspecies *multifoliolata* is scant to none. Comparison of phenology between male and female plants and between land-use types is yet to be done. Understanding the phenology of *Sclerocarya birrea* in Tanzania is important since the populations have been reported to be exceptionally diverse (Kadu *et al.,* 2007) and yet made up of three different subspecies in one geographical area.

2.7.2. Flowering and fruiting

Flowering normally occurs during the end of dry season for subspecies *birrea* and *caffra* with exception of populations in the bimodal rainfall region in Equatorial Africa; flowering records on subspecies *multifoliolata* are limited to none. Records of flowering occurring early than usual in Ethiopia and Burkina Faso (Breintenbach, 1963; Bie *et al.,* 1998) and in South Africa (Shone, 1979) are pointed out by Hall *et al.* (2002). Onset of flowering and the period which trees will continue/remain flowering may not be the same every year due to seasonal fluctuation of weather from one year to another (Hall *et* *al.,* 2002). It has been reported that Devineau (1999) found flowering to last for four months for a population of subspecies *birrea* in Bukina Faso.

Fruiting begins after flowering and therefore automatically follows the flowering pattern. However its timing is variable because it involves the period which they continue to grow on the tree and their respective variation in stages of maturity. Therefore there are populations which will bear fruits into the dry season (Plate 2.3) while others will do so within the wet season (Hall *et al.,* 2002). Records of trees carrying fruits for short durations of time such as two weeks and for long durations of time such as four months have been given by Devineau (1999); and Taylor & Kwerepe (1995). McHardy (2003) in his work on subspecies *caffra* in South Africa recorded, for that particular population and period, a longest fruiting period of 68 days, and a shortest period of 27 days. Other sources reports that fruit fall can last from 1 to 3 months (Lewis, 1987). Flowering and fruiting have a wide inter-annual, population and individual variation than leafing. The amount of fruits produced therefore can vary from one year to another and this has been observed for subspecies *caffra* and *birrea* from Todd (2001) and Mujunga (2000) by Hall *et al.* (2002).

Plate 2.3: Fruiting of subsp. *Multifoliolata* in the dry season

Some trees have been reported to be fruitless in some years. Failure to fruit in some years means that care must be taken when identifying sex of the trees using fruiting as a determinant of females and males.

2.7.3. Fruit production

Fruiting apparently starts at the age of 7-10 years but heavy fruiting is from 15 – 20 years (Janick and Paull, 2008); with yield increasing with age to well over 100 years (Shackleton *et al.,* 2002). Fruit yield vary between trees, populations and seasons. A single marula tree was reported to produce between 21,000 and 91,000 fruits in different heavy fruiting season (Quin, 1959). Leakey *et al* (2005) recorded a record breaking fresh fruit weight of 79 g from what he described as 'wonder tree' in Namibia of which its lightest fruit was 47 g. Their study which was done on 18 sites in South Africa and Namibia concluded that trees on agricultural fields produced heavier fruits than those in the wild population. MacHardy (2003) and Shackleton *et al.* (2005) reports a similar trend for weight and including number of fruits. MacHardy recorded an average fruit weight of 24 g and a maximum of 21,885 fruits per tree for agricultural land population and 3,896 fruits per tree on wild population. Shackleton *et al.* (2005) reported production of >17,000 fruits per tree for trees in agricultural field and <3,500 fruits per tree for wild populations. The variation in fruit yield and phenotypic properties, such as weight and size, between the two environments and seasons may be related to farmers' selection pressure, breeding and domestication influence as well as differences in ecological competition but more data needs to be analysed from a larger sample and from many countries. The amount and weight of fruits produced and the respective fruit sizes for the different subspecies found within a supposedly highest diverse population (Tanzania) for the species is worth comparing.

2.7.4. Reproductive biology

2.7.4.1. Sexuality

Although *Sclerocarya* is dioecious, monoecy have been reported in the studies by Palmer & Pitman (1972-1974); Teichman (1982); Todd (2001) and Mujunga *et al.,* (2002). This is a rare occasion where male trees bear female flowers in one or two of its most proximal inflorescences (Hall *et al.,* 2002). The anomaly occurred in 15 out of 199 trees (Teichman, 1982) and 2 out of 120 and 6 out of 73 trees respectively (Todd, 2001). Palmer & Pitman (1972-1974) and Todd (2001) noted bisexual flowers while Mujunga (2002) noted some pollen bearing anthers on female flowers in Kenya.

2.7.4.2. Anthesis

Mujunga (2000) and Hall *et al.* (2002) reports observations of anthesis based on a subspecies *birrea* population in Kenya. Individual female flowers were in a fully open state from 0800 to 1200 hrs local time. Stigmas of newly opened flowers which are normally one day old were white and cream in colour and the lobes were less flexed than the flowers that have been open for longer. Stigmas remained receptive for up to 4 days but turned brown after 5 to 6 days, and petals started to wither and also turned brown. After fertilisation, secretion of nectar stopped. Some female flowers which would have been borne aborted ended up being eaten by predators like birds. Petals, androecium, pistil and sepals wilted in succession after fertilisation. The maturation and opening of male flowers followed an acropetal sequence, with the most opening between dawn and midday and the peak opening period from 0700-0900 hours local time. Anthers dehisced 32 hours after flower-opening. After dehiscence, pollen viability remained high for at least 12 hours and after 48 hours almost 50% still remained viable. Viability was lost mostly after 120 hours with the whole process of anthesis lasting for 6 – 14 days.

2.7.3.3. Pollination

Sclerocarya is entomophilous meaning it produce sticky pollen grains and secreting nectar. *Sclerocarya birrea* enjoy a variety of pollinators although *Apis mellifera* is usually cited as the main pollinator for subspecies *birrea* and *caffra* (Taylor, 1942; Breitenbach, 1963; Palmer & Pitman, 1972-1974; Storrs, 1979; Clauss, 1984). Flower visitation by pollinators is usually during cool periods of the day especially mid-morning and natural pollination was found to be successful (56%) than assisted pollination (35%) most probably due to timing (Munjuga, 2000; Hall *et al.,* 2002).

In some societies marula is used for firewood and a source of edible caterpillars. In such areas cutting whole or branches of male trees is common whereas the female trees are left for fruit production. This situation is reported to be promoted by both farmers and extensionists (Leakey *et al.,* 2005) but it will eventually reduce pollination potential and therefore affecting marula population structure and density. Reduced pollination due to harvesting for wood and caterpillars can result in reduced abundance of the marula populations. This will affect supply of resources as well affecting the ecological role played by the tree.

2.8. Propagation and cultivation of *Sclerocarya birrea*

Propagation of *Sclerocarya birrea* can be through natural or artificial means. Natural regeneration can be through seeds or coppices from roots and stems. Artificial means can be through seeds, marcoting, cuttings or grafting both in the nursery or field/wild conditions. However most of the *Sclerocarya* trees are a result of natural recruitment, only a few cases of farmers have been reported to have planted the tree. Shackleton *et al.* (2005) reports that a little less than one-third of interviewed farmers planted *Sclerocarya birrea* in their yards, whereas approximately half of them nurtured new seedlings that they found growing in suitable positions in the home yard. When planting, most people used a seed that was harvested from trees in the wild or from neighbours' trees. Many also used either a truncheon harvested from a tree with desirable traits, or transplanted a seedling they had observed growing in the wild or elsewhere in the village. The higher density of adult female trees in homestead plots is a result of active planting of new trees, as well as passive protection and nurturing of self-seeded recruits. Propagation of the subspecies by farmers in Tanzania, which might affect availability and occurrence, have never been studied or compared. For a crop intended for domestication like *Sclerocarya birrea*, horticultural properties of its genotypes need to be known (Hillman *et al.,* 2008); such properties may be appropriate propagation methods, yield, etc.

After establishment *Sclerocarya birrea* does not need soil amendment/improvement interventions compared to other conventional cultivated fruits trees such as its close relative, *Mangifera indica*. Akinnifesi *et al.* (2008b) discovered that use of manure, fertilisers and irrigation does not improve performance of *Sclerocarya birrea* seedlings; instead its growth is reduced by such treatments. They associate their results with the fact that woodland conditions where the species occurs are usually stressful in terms of availability of water and nutrients. Management of the trees by farmers should therefore be fairly cheap since the input requirement in terms of labour and materials is minimum.

2.8.1 Natural regeneration

This is the main source of most of the existing *Sclerocarya* crop both on agricultural and wild environment. It is common to find young seedlings under mother trees soon after rains begin but most of them die afterwards due to damage by grazing animals, removal during land tillage and competition (Gouwakinnou *et al.,* 2009). Seed germinate readily once the opercula is opened or weakened mainly after exposure to soil surface conditions allowing moisture to penetrate. Under field conditions, regeneration maybe slowed by damages of the seed or nut by fire, insects and fungi. To maximize the amount of seedlings reaching sapling stage suggestions have been made. They include uprooting of some seedlings to leave the number and spacing required, construction of water harvesting structures around seedlings, protection from browsing animals by fencing and provision of regular weeding (Hall *et al.,* 2002).

2.8.2. Artificial regeneration

Like many other useful indigenous trees in woodlands, there have been few attempts to propagate *Sclerocarya birrea* in the nursery or to transplant into fields (Akinnifesi *et al.*, 2006; Chirwa *et al.*, 2007; Akinnifesi *et al.*, 2008b). Artificial propagation using seeds is complex because of several issues. Germination rates are low requiring proper seed storage and pre-treatment (Mojeremane & Tshwenyane, 2004). Secondly predicting the sex of the resulting seedling is impossible and may result into males which won't bear fruit and hence jeopardizing those with fruit production as an objective. Vegetative propagation using cuttings and grafting is therefore the best option for *Sclerocarya birrea*. However when this is done in the nursery care must be taken to avoid root damages because the species have a fast elongating tap root.

2.8.2.1. Propagation from seeds

Seeds of *Sclerocarya birrea* are held in large stony oval shaped nut/shell which weighs up to 12g. Each nut has 2 to 4 seeds in cavities closed by an operculum which can be removed mechanically or naturally. To induce germination fruit skin and pulp are removed, nuts dried for at least 7 days and operculum removed or loosened careful using a knife or chisel. Alternatively the nuts can be soaked in water for 12-24 hours but not for 36 hours (Hall *et al,* 2002). For mass production of seeds a mixture of fruits and gravel (in a ratio of 2 fruits: 1 gravel) soaked in water may be churned in a concrete mixer. Alternatively a mixture of fruits with coarse sand in water can be pounded in a mortar. The retrieved endocarps are removed, and the nuts are sun-dried for two days (Msanga, 1998).

Germination of *Sclerocarya* can take place just after 4 days but can go up to weeks and success is widely variable. An attempt to scarify the nuts using sulfuric acid showed no significant influence on germination (Teichman *et al.,* 1986). Different levels of moisture of the seeds also indicated minor variations in germination success (Teichman *et al.,* 1986; Were & Munjuga, 1998). Intact nuts tested under light and dark conditions did not germinate but de-operculated nuts germinated more (73%) under light conditions than under dark conditions (49%), (Teichman *et al.,* 1986), most probably because the germination of *Sclerocarya* is epigeal. Soaking in hot water did not show improvement (Shone, 1979) but cold water soaking gave 40% germination success (Mbuya *et al.,* 1994) and success in shortening germination period increased when soaked seeds were de-operculated (Msanga, 1998). Long time storage also has shown to increase germination success. Storage of 1 to 2 years resulted in higher germination success (>80%) after six days than 1 to 2 months storage which resulted into 50% success in the same duration (Teichman *et al.,* 1986; Were & Munjuga, 1998; Hall *et al.,* 2002).

Germination of *Sclerocarya* seeds is epigeal and best results are obtained when sowing is done at the onset or rain seasons (Nikema *et al.,* 1993; Hall *et al.,* 2002). Seedlings need to reach knee height before field transplantation. Duration to reach this height varies from 2 to 6 months depending on treatment, climate, substrate and watering regime (Nikema *et al.,* 1993; Hall *et al.,* 2002). Due to seedling handling and transplantation problems which may result from root damage and field shock, direct sowing has been suggested to be the best solution (Hall *et al.,* 2002).

2.8.2.2. Vegetative Propagation

Vegetative propagation of *Sclerocarya birrea* is important in two main reasons. Firstly, since the plant is dioecious, planters may want to have more female, fruit bearing trees, than male pollinators. Secondly, the fruit quality of trees varies greatly and some of this existing genetic diversity can be captured by using vegetative propagation methods (Mbuya *et al.,* 1994). However due to the length of time and seed processing/treatment labor required to generate seedlings, grafting from seedling sounds a difficult approach to be carried out by farmers (Shone, 1979). Branch cuttings from juvenile wood, truncheons, budding, air layering, root severance and grafting are suggested to be tested for *Sclerocarya birrea* as means for vegetative propagation (Maruzane *et al.*, 2002; Hall *et al.*, 2002).

Grafting has been reported to be successful in Botswana, South Africa and Zimbabwe (Hall *et al.*, 2002). Grafted scion produced fruits after 4 years, with one case fruiting in two years (Taylor & Kwerepe, 1995) while Maundu *et al.*, (1999) observed fruiting from grafting after 3 years. Two methods can be used in grafting, top wedge or whip grafting. Success is high, up to 95% (Hall *et al.*, 2002) when the following are observed: 1. Grafting immediately after bud dormancy break using scion from tips of branches, 2. Use of sharp knife, 3. Collection of scion early in the morning or late in the evening when temperatures are low, 4. Use seedlings which is at least pencil thick and scion-root stock compatibility ensured, 5. Leaves are removed from the scion while retaining few on the root stock, 6. Follow normal procedures for top wedge or whip grafting, cover the plant after grafting with plastic bag or put it under shade, 7. Remove the plastic cover after 6 – 8 weeks (Holtzhausen *et al.*, 1990; Taylor & Kwerepe, 1995; Maruzane *et al.*, 2002; Mateke & Tshikae, 2002; Hall *et al.*, 2002).

The use of cuttings is not complicated and usually very successful when taken from young plants (Hall *et al.*, 2002). However since it is impossible to determine sex of seedlings this success from cuttings is rendered useless due to the species' dioecy although they may be used to produce root stock for grafting. More successful than small leafy cuttings from immature plants is propagation through truncheons. They should be 10 cm in diameter and 2 m long and 0.6 m portion buried in the soil keeping the environment damp (Shone, 1979). However other dimensions have been suggested by Taylor & Kwerepe (1995) for slender (5 cm) diameter and Wyk (1972-1974) for wider (15 cm) diameter.

These previous propagation trials and experiments involve skills and costs which are difficult to be met by ordinary poor farmers. They also report methods and rates of success which are contradictory. The domestication of indigenous trees in Africa continue to fail because among other reasons cost effective and practical propagation methods have not been developed and given to farmers (Amri *et al.,* 2010). For domestication programs involving *Sclerocarya birrea,* finding a solution to this area is important.

2.9. Uses of *Sclerocarya birrea*

2.9.1. History of use

Sclerocarya birrea has been known and used by man for many years and some authors report recovery of endocarp material from archeological deposits in Zimbabwe aged 150,000 years suggesting its usage around the time of *Homo sapiens* speciation. A wider acceptance usage and in a form of organized exploitation however is of much younger material aged 9,000-11,000 years from Zimbabwe (Walker, 1989). This is believed to be the period when mankind was changing from nomadic to settlement system of life becoming selective to species useful to them especially for food and medicine where *Sclerocarya* was one of them. Through the process of selection, domestication evolved (Diamond, 1997) and due to significance of *Sclerocarya,* tools to extract its kernel from the endocarp were developed. Fragments of endocarp dated around 1,000 years old in both southern (Palmer and Pitman, 1972-1974) and western Africa (Neumann *et al.,* 1998) testify use of tools to extract kernels, presumably for their oil (Hall *et al.,* 2002). Preparation of fermented beverages from *Sclerocarya birrea* fruits followed the development of pot making skills and early awareness that some trees were superior to others, for larger crops of preferred quality, leading to the emergence of the distinctive cultural significance of the tree. The strength of 'morula culture' (Krige, 1937) has prompted suggestions that brewing skills and systematic use of *Sclerocarya birrea* trees date back many centuries (Palmer and Pitman, 1972-1974, Hall *et al.,*2002).

2.9.2. Local use of fruits and kernels

2.9.2.1. Use of Fruits

Sclerocarya birrea fruit and kernels form an important component of the diet of rural people (Liengme 1981, Cunningham 1988, Shackleton *et al.,* 2000). Fresh fruit is widely consumed, particularly by children (Cunningham 1988, McGregor 1995, Cavendish 1999), providing a rich source of vitamin C. Availability of the fruits during months of food scarcity makes it even more important as a substitute food source. Fruits are also collected and processed into juice, alcoholic beverages (wine and beer) and jam, extending the shelf life of the product and prolonging availability and consumption beyond the two to three month fruiting season. It has been reported that marula beer can be stored for up to two or three years if sealed in clay or plastic containers and buried underground (Shone 1979, Shackleton *et al.* 2000). In West Africa, the juice is boiled down to a thick black consistency and used for sweetening porridge (Dalziel 1948, Palmer & Pitman, 1961). The use of marula juice as an additive to variety of sorghum, maize and millet porridges has also been recorded for tribes in South Africa by Quin (1959).

Data from Bushbuckridge, South Africa indicate that *S. birrea* is amongst the most commonly used wild fruit species, with 59 – 77 % of households reporting consuming marula fruits between four to five times per week during fruiting season (Shackleton, 1996; Shackleton *et al.,* 2000). This figure does not include opportunistic consumption by children when they are away from the homestead, either herding livestock or walking to and from school, so consumption rates are likely to be considerably higher. In the same area, about 2% of households sell marula products, mainly beer and kernels (Shackleton 1996). Similar high frequencies of fruit use for subsistence purposes (between 83 – 100 % of population) are reflected in a report from northern KwaZulu-Natal, South Africa, Inhaca Island, Mozambique, and Zimbabwe (DFID, 2003). Research on the use of wild plants in the Goba area of the Lebombo Mountains, Mozambique also highlights the popularity of marula for household use. Using pairwise ranking, *Sclerocarya birrea* emerged, after *Trichelia emetica* and *Strychnos madagascarensis,* as one of the most preferred fruit species out of a total of 34 species (Bandeira *et al.,* 1999). However, this popularity is not consistent across the region. In Malawi, for instance, the fruit appears to be much less frequently used than in other southern African countries and a study on indigenous fruit trees in this country indicated that *Sclrtocarya birrea* was not ranked as an important species (Ngulube, 2000). Similarly, in the Kavango region of Namibia, *Sclerocarya birrea* is sometimes used to make a distilled alcohol but almost never used for beer or juice. Fresh fruits are never eaten in this region and the nuts are seldom extracted (du Plessis, 2002).

Ireland (1999) found that households harvested an average of 36 kg of marula fruits per season in Makua village, whilst the average household consumption rate was only 4.5

kg in nearby Manganeng. She attributed this difference to the much greater effort required to collect fruit in Manganeng, South Africa. In this village there are no *Sclerocarya birrea* trees in or close to the village, therefore requiring them to walk long distances. The gross annual value of marula fruit use was estimated to be US$41 and US$7 per household for each village respectively (Ireland, 1999). In both villages marula fruit was collected in greater amounts than any other wild resource.

A number of resource valuation studies have indicated that indigenous fruits, after fuelwood and wild vegetables, contribute a significant proportion to the overall economic value of wild resources consumed by households (Cavendish, 1999, Shackleton and Shackleton, 2000; Shackleton *et al.,* 2005). Most of the value of these indigenous fruits can be attributed to marula products, and it is expected that a similar pattern would apply in other areas where *Sclerocarya birrea* is dominant. Another study reports that the average annual value of marula products harvested from trees on home plots and fields was estimated at US$116 per annum (High and Shackleton, 2000). This is the value of unprocessed fruits mostly derived from the use of fruits in place for food. Households also tend to trade on beer and wine products.

The household economic value for *Sclerocarya birrea* in Tanzania is not known. In this country there is an opportunity to compare not only the household economic value, but also the values of the subspecies.

2.9.2.2. Making and uses of beer

The process to brew the alcohol varies from region to region and between communities and ethnic groups (Quin 1959, Shone 1979, Liengme 1981). Basically the skins are slit with a knife or fork (often made from bone in the past) and the fruits squeezed over a clay pot or plastic container to release the flesh and juice. Water is added and the container placed in a warm place. The thick scum that forms on the surface is removed after one day, and the fruits worked through again to remove the pips. The juice is then left to ferment in an airtight container for a few days before it is ready to drink. In some cases the skins are left on the fruits at the initial step and removed later (Liengme 1981). Sugar is sometimes added to speed up fermentation and to sweeten the beer. Households sometimes reserve a portion of the brew, which is buried underground and kept until Christmas or Easter when the men working in cities retreat to their home villages for holidays. The sediment produced during the brewing process is reported to have aphrodisiac properties and may be drunk by men to enhance their libido (Shackleton *et al.,* 2003). Indeed, the marula season coincides with one of the few times of the year when most male migrant workers are home (Shackleton *et al.* 1995). Thus, drinking parties are not just social events, but a time for renewing relationships and planning the year ahead. So popular is the beer, that in the past, certain communities had a ruling that no man may carry arms during the beer season for fear of the damage he may do his neighbour whilst under the influence of this intoxicating drink (Palmer and Pitman, 1961).

2.9.2.3. Use of kernels and oils

S. birrea nuts are processed by women for both home use and sale. The 2-3 nutritious oil and protein rich kernels are extracted manually from the pulps using a range of techniques specific to different communities accross the plant's distribution range. In some areas decortication is achieved by cracking the nuts against a stone slab, and then removing the kernels individually with a sharp needle-like tool (Cunningham, 1988). The hard rock required for the "hammer" and "anvil" is a hard volcanic rock. Persistent cracking results in pits in the rock, which increase in number as some pits get too deep and new ones started (Cunningham, 1988). In areas where households do not have access to hard rocks other techniques are used. For example, the marula nuts are cracked against an axe blade (or other large piece of iron) using a block of hard wood. In other cases the opposite action is used. An axe is used to cut open the operculum end of the pip whilst it rests on a wooden block, and thereafter a small piece of metal, such as a flattened nail, is used to prise out the kernel (Lombard *et al.,* 2000). In other areas the nuts are boiled or heated in the fire prior to decortications (Lombard *et al*., 2000). This is said to make extraction simpler as the lids of the fruit locules come off more easily (von Tiechman, 1983). The sharp tools used to extract the kernels vary and may be made from metal, bone or a thorn. Whatever the process used, hand extraction is a skilled and arduous task as the shells are hard, and if the kernels are to be sold, they need to be whole. Gumbo *et al.* (1990) recorded approximately 24 working hours to fill an 800 g tin with kernels. Research on the marketing of wild products in Zimbabwe revealed that the *S. birrea* nut market was one of the few wild resource markets limited by supply (Campbell and Brigham, 1993; Brigham *et al.,* 1996). Therefore if technical constraints on extraction could be overcome, this product has a considerable market and income generation potential. However, it is the difficult extraction process and high labour input that gives the kernels a relatively high value on the market. Indeed, some stakeholders are concerned that improved technology could result in an important value-adding step being removed from households to more centralised facilities (Lombard *et al.*, 2000).

Data on the use of the nut resource are very variable across the range of *Sclerocarya birrea*. In some areas, kernels appear to be little used despite their nutritional properties and potential cash value. Shackleton *et al.* (2002) reports that in an area in South Africa, where marula is found, only 11% of the population extract and use nuts. In Zimbabwe, McGregor (1995) found only one household (2 % of the sample) that extracted *S. birrea* kernels, and this was on an occasional basis while in Kavango, Namibia the nuts are almost never used. By contrast, marula nuts form an important dietary supplement, especially for poorer and elderly households, on the sandy coastal plains of Inhambane Province and Inhaca Island, Mozambique (Cunningham *et al.* unpubl.). Up to 100% of people in Owambo (Namibia), Northern KwaZulu-Natal (South Africa) and Mbengarewa (Zimbabwe) use kernels (Cunningham *et al.*, 1992).

Kernels are either roasted or eaten raw as a snack, or mixed with wild herbs and served as a relish with the main meal. Quin (1959) reports how the Pedi of Sekhukhuneland used marula embryos to flavour a green leaf relish. Kernels are also ground into a powder and mixed with sorghum stew (Quin, 1959) and soups (Peters, 1988), or stamped to form a cake which can be eaten alone (Peters, 1988). The kernels can be stored for several months, and Krige (1937) reports how the Phalaborwa of South Africa subsisted largely on a diet of stored kernels mixed with wild herbs or meat during the dry season.

In Namibia oil is traditionally extracted from the kernel with a pestle and mortar aided by careful use of small amounts of warm water. The oil and cake thus prepared can be used for at least one year. Other uses of the kernels include as a meat preservative (Palmer and Pitman 1972; Peters 1988; Holtzhausen, 1993) and as a source of oil for skin moisturiser (Coates Palgrave 1972; van Wyk and Gericke, 2000). The oil is easily absorbed, has high proportions of oleic acid, as well as the essential linoleic fatty acid (4-7%); which combine to make the oil ideal for topical application. Marula oil has also shown to improve skin hydration, skin smoothness and reduce redness (Gruenwald, 2006). Traditionally, Zulu people reportedly crush the nuts and boil them with water, skimming off the oil, which they massage, into the skin as a cosmetic (Coates Palgrave 1972). In the past this oil was used to preserve and soften the traditional skin shirts that they used to wear (Watt and Breyer-Brandwijk, 1962). A similar use was also observed in Namibia (Rodin, 1985). It is this indigenous knowledge upon which current marula oil commercialisation initiatives have built. Kernels have also been used as illuminants and apparently burn with a bright flame (Palmer and Pitman, 1961; SEPASAL, 2001). The gift of kernels is considered a mark of great friendship (Palmer and Pitman, 1961).

2.9.3. Opportunities and challenges for use of fruits and kernels

Despite the key role played by marula and other wild fruits in rural households, there is evidence that use may be declining in some areas in favour of exotic fruits (Gomez 1988; McGregor, 1995). However, exotic fruits resources may be expensive to buy or cultivate in some areas requiring intensive protection against disease and pests compared to wild indigenous resources. Few individuals can afford the cost of purchasing commercially grown fruits, and most of the land is small and dry to cultivate these exotic fruits (Shackleton *et al.,* 2000). Clarke *et al.* (1996) suggested that a decline in the use of fruit and nuts of *S. birrea* in Zimbabwe could be due to the absence of nut cracking technologies, and the same factor may explain the reduction in the frequency of wild fruit porridges observed by McGregor (1995). The status of the population across its geographical range needs to be checked because it can affect trends of utilisation. In Namibia long history of use is changing because the remaining populations are found in private farmlands, with the wild populations almost diminished. Farmers without the trees on their farms are required to buy or ask from neighbours contrary to free collection in the past. Stealing fruits from other people's farms as a result of scarcity of the trees in Namibia have been reported by McHardy *et al.* (2003).

2.9.4. Trade and income generation from fruits and kernels

Over the past few decades there has been a noticeable growth in the local (endogenous) trade of marula and other wild products as household demands for disposable income increase (McGregor 1995; Brigham *et al.,* 1996; Shackleton *et al.,* 2000; DFID, 2003). Traditionally, across a range of ethnic groupings, the sale of marula beer and other products has been strictly a taboo. Whilst this appears to have become largely redundant, there are still some areas, such as northern Maputaland in South Africa, where such customary norms continue to be respected (Cunningham, 1989). Cases in which men have refused to allow their wives to sell beer have also been recorded (Shackleton *et al.,* 1995). It is not understood whether the use of the particular subspecies varies within the communities where they occur. However variation of traditional local knowledge can play a vital role on trade and uses of the tree. It may therefore be useful to analyse and transfer/exchange local knowledge held by different communities in order to optimize beneficial utilization of this valuable and multipurpose species.

Women are mainly involved in trading in marula products, and income from sales tends to be highly variable (Shackleton *et al.,* 2000). In Bushbuckridge (South Africa), Shackleton *et al.* (2000) found that some 15 % of households surveyed were trading in various indigenous fruit (both processed and raw) earning on average between US$87 and US$149 per annum. The principal fruits/fruit products sold were from *S. birrea*, *Strychnos madagascariensis* and *Strychnos spinosa* and most trading took place in summer (73 % of traders). The most profitable business reported an income of as much as US$820 per month for a limited period from selling *S. birrea* beer during winter (Shackleton *et al.,* 2000).

There are clear indicators that trade in marula and other wild plant product is increasing. For example, in the 2000/2001 marula season over eight marula beer stalls on a 10-20 km stretch of road between Bushbuckridge and Thulamahashe were observed. Such roadside vendors were rarely seen a few years back. Beer was selling for slightly less than £0.5 per two litre bottle at these stalls. A similar trend has been observed in Namibia where in the past marula beer was made only for home consumption, but now can be found for sale in most street markets. Prices vary according to location and proximity to the resource. For example, one litre of beer sells for £0.12 in rural areas, £0.18 in urban markets within the production area and up to £0.5 in distant urban centres far from the production areas (Shackleton *et al.,* 2002). There are also reports of marula beer and wine being sold in Zimbabwe (Gumbo *et al.,* 1990), Swaziland (Edje, 2000), the former Venda, South Africa (Mabogo, 1990) and in Mali (D. Sidibe *pers. Comm.*). Kernels are also often sold and fetch much higher prices than fruits on the local market at US$3.71/kg as opposed to US$0.02/kg for fruits (Shackleton and Shackleton, 2000). According to informants in Dodoma district of Tanzania, fruits are sold at local market at US $0.20 per kilogram (Teklehaimanot, 2005). Of all indeginous fruit trees (IFTs) products in Africa, Amarula cream made from *Sclerocarya birrea* fruits in South Africa is the only one to break into the international market (Akinifesi *et al.,* 2008a) and is the second best seller after the Irish Baileys cream.

2.9.5. Use and trade in carving wood

Marula wood has been traditionally used for carving pestles and mortars, bowls, drums, beehives and stools (Dalziel, 1948; Watt and Bryer-Brandwijk, 1962; Mbuya *et al.,* 1994; Clarke *et al*., 1996) and even, in some areas (e.g. Malawi), for making canoes (Coates Palgrave, 1956). In Madagascar the wood is used to make ox-wagon wheels (DFID, 2003). It is a soft, splinter free wood that is easily carved, but tends to be susceptible to infestations by woodborers (Watt and Breyer-Brandwijk, 1962), Lyctus beetle and sap stain fungi (Immelman *et al.,* 1973). A survey of *S. birrea* use in three southern African countries revealed that in Mbengarewa (western Zimbabwe) 55 % of households use marula wood to make utensils, whereas none in northern KwaZulu Natal or Inhaca Island use the wood for this purpose (DFID, 2003). In the Mutanda Resettlement Area, Zimbabwe, *S. birrea* form one of the three most popular species for making musical instruments (Grundy *et al*., 1993).

In the region bordering the Kruger National Park in South Africa, *S. birrea* forms the highest volume of wood used in the growing local woodcarving industry (Steenkamp, 1999). In 1998 approximately 33 cubic metres of marula wood entered the market in this area (Steenkamp, 1999). Trees are harvested to carve animal figurines (giraffes, leopards and antelope) ranging in size from less than 30 cm to more than 2 m tall. These are sold mainly at the roadside to tourists (Steenkamp, 1999). The carvers purport to use only male trees, but local community members declare that female trees are also being harvested as pressure on the existing resource base increases (DFID, 2003). This potential conflict of interests is of concern to development workers in the region, particularly since marula fruits are not just important for household consumption but are also being widely traded. The use of marula for commercial carving has also been reported in Zimbabwe (Braedt and Standa-Gunda, 2000).

There are various reports that *S. birrea* was used extensively during colonial times for manufacturing tomato boxes and toilet seats (Palmer and Pitman 1961, Shone 1979). Other uses for the wood include furniture, panelling, flooring, laminated products, box shooks and manufactured articles such as shoe heels (Immelman *et al.* 1973).

2.9.6. Use of other marula products

The shells of marula nuts are often used as kindling and are a good source of fuel (Lombard *et al.,* 2000). Some women report that the hot nuts provide an effective heat source to use in coal irons (Lombard *et al.,* 2000). Dried nuts may also be used to make necklaces that traditionally symbolise love.

Wood from male trees is sometimes used for firewood. Indeed, extension officers have been reported to encourage the use of male trees for this purpose, in spite of customary laws that prevent felling (Shackleton, 1993). Quantitative work has indicated that the use of marula for fuelwood is relatively high in some areas. It was found that 97 % of households in Sihangwane, Northern Kwazulu-Natal were using marula for fuelwood, as were 65 % in Zimbabwe (DFID, 2003). In the case of the latter, the wood was mainly used for burning bricks, in contrast, none of the people interviewed on Inhaca Island were using marula as fuelwood. In some parts of southern Africa removal of male trees has been so severe that female trees have ceased to be productive and so are also felled. Use of these trees for fuelwood indicates overwhelmed pressure on woodland fuelwood species because the fuel value for *Sclerocarya birrea* wood is relatively very poor compared to other trees (Mbuya *et al.,* 1994).

The bark has medicinal properties and is used widely in treating dysentery and diarrhoea, rheumatism, gangrenous rectitis, insect bites, burns, tuberculosis and a variety of other ailments (Dalziel 1948; Watt and Breyer- Brandwijk 1962; Khan and Nkanya 1990; Kokwaro 1993; Hutchings *et al.,* 1996; Morris 1996; Lombard *et al.,* 2000; Mathabe *et al.,* 2006; Iwalewa *et al.,* 2007; de Wet *et al.,* 2010). In the Zomba district of Malawi an infusion of the bark is used for treating coughs and throat infections (Morris, 1996). Medicinal uses of the root are also numerous. Decoctions, infusions or steam from boiled roots are used to treat heavy menstruation, bilharzia, coughs, weakness, sore eyes, heart pains and as an antiemetic (Gelfand *et al.,* 1985). Extracts from the leaves provides a remedy for abscesses, spider bites and burns. The leaves are also used as a sedative (Descheemaeker, 1979) and cooked as relish in some communities. Both bark and leaves are said to have antiseptic and astringent properties (Jenkins 1987; Khan and Nkanya, 1990). Previous tests on crude extracts of marula bark found weak pharmacological activity in respect to hyper-tension, anti-inflammation and pain killing (von Teichman 1983) but recently they have been found to be very effective in treatment of diabetes (Dieye *et al.,* 2008; Ndifossap *et al.,* 2010) and inhibit intracellular caffeine-induced Ca2+ release from skeletal muscle sarcoplasmic reticulum (Belemtougri *et al.,* 2001). The use of bark as a malaria prophylactic or cure has been widely reported, although there is, as yet, no pharmacological evidence to support its efficacy in malaria treatment (Watt and Breyer-Brandwijk, 1962; Morris 1996; van Wyk and Gericke, 2000). To treat diarrhoea a community in South Africa crushes the bark of subspecies *cafra* and mix it with hot, warm or cold water. The infusion is administered anally or orally. The infusion (125 ml) is drunk three times a day, until diarrhoea subsides. If administered anally the dosage depends on the person's weight (de Wet *et al.,* 2010).

As well as medicinal uses, there are reports of the bark being used as an insecticide in Tanzania (Khan & Nkanya, 1990). The fruits are used by the Zulus as an insecticide particularly for destroying ticks (SEPASAL, 2001). Venda women are said to use ground bark mixed with soft porridge to wean and strengthen their babies. The frequency of use and amounts of bark and leaves used for medicinal purposes appears to be relatively low. In one area in South Africa, survey revealed that only a relatively small percentage of households use marula products for medicinal purposes. However, this is an area where almost no quantitative data exists (DFID, 2003).

The gum secreted by *Sclerocarya birrea* is rich in tannin and is used to make ink by dissolving it in water and adding soot (Dalziel, 1948; Watt & Breyer-Brandwijk, 1962; FAO, 1995). The San of Namibia and Botswana use marula gum as a carrier for a poison made from crushed *Polyclada* beetle larvae. This is applied to the tips of their hunting arrows. In Northern KwaZulu-Natal the bark of *Sclerocarya birrea* is sometimes used for dying ilala palm leaves prior to weaving (van Wyk & Gericke, 2000) or fish nets (Pooley, 1980). The colours obtained are generally shades of mauve, pink, brown or red (van Wyk & Gericke, 2000).

Sclerocarya birrea is one of the primary hosts for the parasitic mistletoes that produce "woodroses". Woodroses are flower-like, woody outgrowths produced in response to the parasite. They are harvested and sold as curios providing income to collectors (Dzerefos, 1996). The species is also host to a variety of butterflies and moths which produce large, edible saturniid caterpillars (Pooley, 1980; 1993). These caterpillars are collected, their skins spilt and the insides squeezed into a pot. The contents are then roasted and eaten. The cerambycid woodboring beetle larvae that occur under the bark of *S. birrea* trees are also commonly consumed (Dalziel, 1948; Pooley, 1980; 1993; Cunningham, 1985). They are found by tapping the tree until a hollow sound indicates a hole, which is then investigated and the larvae extracted (Pooley, 1980). These larvae are cooked in their own fat. The fruits and leaves provide nutritious fodder for livestock especially during the winter months (Holtzhausen, 1993; Teklehaimanot, 2008).

2.9.7. Variation of uses between closely located populations

Uses of *Sclerocarya birrea* vary even as close as between neighbouring villages. Specific reasons for these variations have not been given although they seem to relate to differences in culture, traditional knowledge and scale of availability of the species. A study by Nghitoolwa *et al.* (2003) found out that there is a difference in size and sex distribution between *Sclerocarya* populations in two villages in Namibia. This suggests a possibility of use history and habit; shaping the composition of the populations differently among communities even if their location is a few kilometres apart.

Report from a DFID (2003) project conducted in more than 15 villages in South Africa and Namibia gave the following results.

- In Maputaland in North eastern South Africa utilisation of marula is almost entirely traditional, i.e. eating of fresh fruit, making of beer, extraction of kernels and use of bark, leaves and roots for "muti" with zero use for juice or jam. Many people than expected eat fresh fruits but selling of beer is limited because of cultural norms and therefore beer is made for household consumption only. They reported stealing of the fruits as well as lack of trade in some villages due to relatively abundance of the fruits. Fruits are collected mainly by women who spend up to an hour to collect 150kg of fruits from communal lands, yard or farmers fields.

- On the other hand, in Makhatini and Bushbuckridge in South Africa extensive use was made of a wide range of marula products including fruit, juice, beer/wine, kernels and wood. Of particular significance were the neighbourhood marula parties where the beer/wine was drunk. These are important in building social networks and reciprocal relations, and are a key form of social capital. The potential demise of these 'get-togethers' was one of the main concerns linked to marula commercialisation. In Bushbuckridge, jam was made although it is non tradition but was introduced in the area by external agencies. Producing households made about 5 litres of jam per household most of which was used for home consumption, few who sold it earned as little as £4.40 per season.

- Ovamboland in North-Central Namibia use was made of a wide range of marula products including fruit, juice, beer/wine, kernels and wood and in addition extracting oil from kernels. The cake made from the residue after oil extraction was also widely consumed or fed to livestock. They also had the neighbourhood marula parties for beer/wine with similar significance in building social interactions and wellbeing. In Namibia cosmetics were also made from marula fruits. They also report scarcity of marula trees in Namibia compared to South Africa. As a result, supplies of fruits in South Africa is from communal land while in Namibia is from private lands and therefore presence of marula fruit trade in Namibia. So for South Africa and Namibia trade is for all products except that there is no sale of fruits between farmers in South Africa (DFID, 2003). The situation in Namibia raises concerns that scarcity of the resource is destroying its social value since it will be owned by few individuals and hence no access to everyone.

- The use of marula wood for fuelwood was high in some sites (60 % - 97 % of households), although in most cases respondents said they used dead wood or wood generated from tree pruning on home plots and fields rather than live wood. Use was also reported to be infrequent or rare in some cases. A few households in Bushbuckridge indicated that they sometimes cut male trees, while other households in both Busbuckridge, South Africa and Namibia mentioned that they may cut a weak or unhealthy female tree or harvest branches from trees infected by parasites. In Makhatini, South Africa 37 % of households indicated that they had never used marula wood for burning, whereas this was only 2 % in Busbuckridge (DFID, 2003).

- Marula wood was not widely used for fencing, poles or utensils in either of the South African sites as the quality was said to be too poor for these purposes (about 10 % in South Africa). However, it was more important in Namibia (52 % - utensils and 78 % - poles). The reason for this difference is again unknown, but may be due to a lack of alternative species in the Namibian site where communal lands for wood harvesting are virtually non-existent (den Adel, 2002). The types of utensils made included spoons, rough seats/stools, food trays for pigs, hoe handles, catapults and pestles and mortars. A few households in Bushbuckridge and Makhatini mentioned purchasing spoons, whilst none in Namibia had bought marula wood products (DFID, 2003).

- In all villages sampled, carving of marula wood was not widely practiced. However, in the Nsikasi area neighbouring Bushbuckridge this species forms the basis of a large softwood curio industry. In Makhatini, five households were found to manufacture a range of carved utility items such as trays, basins, decorative spoons, plates and meat platters from marula wood. The latter were sold by one carver for £2.20 each (DFID, 2003).

- The tree was also used for medicinal purposes to treat coughs and stomach ailments where in Namibia leaves are more preferred while in South Africa barks and roots are a preference. This shows that in Namibia where the resource is scarce, wise use have evolved compared to South Africa where the resource is plenty and people obtaining it from communal land. The study also reports some changes in trends of use due to environmental; and cultural changes. Use of hair relaxer (cosmetics) and caterpillars (food) in Namibia has declined probably due to shrinkage of population in the wild. Also introduction of 'born again' Christian churches limits use of marula beer while younger generation claims to lack knowledge which was held by their elders. Commercial sales are also done for both the kernel and fruit especially in South Africa (DFID, 2003); principle buyers are cosmetic and cream manufacturers such as Marula Natural Products (Pty) Ltd.

From this synthesis it is evident that the use of marula products varies even between small geographical separations. Assessment of how different communities within Tanzania use products from the species can also result in documentation of variations in knowledge and uses.

2.10. Nutritional value of *Sclerocarya birrea*

The most valuable asset of *Sclerocarya birrea* is the fruit (Akinnifesi *et al.,* 2008a) and recognition of the species as an important food source for rural communities has generated much interest in the nutritional values of the plant and potential for product development (Peters, 1988; Mojeremane & Tshwenyane, 2004). Leaves are also cooked as a relish in some areas (Fox and Young, 1982). The properties of the most important parts of the fruit - the flesh, pulp and kernel have been studied by many researchers for years. However the volatile constituents of *Sclerocarya* fruits are poorly studied (Viljoen *et al.,* 2008).

2.10.1. Raw products

2.10.1.1. Flesh

The flesh of marula has extremely high contents of vitamin C, up to 2 mg g^{-1} fresh juice which is four times higher than that of orange (Fox and Stone, 1938; Shone, 1979; Peters, 1988; Eromosele *et al.,* 1991; Jaenicke & Thiong'o, 2000; Shackleton *et al.,* 2002). It has been reported that an outbreak of scurvy in 1937 in a district in south Africa was significantly lowered after fruiting season of marula resumed (Shone, 1979; Hall *et al.,* 2002). An unpublished data (from an M. Sc. dissertation) on unspecified subspecies from Tanzania reports 0.06 mg g^{-1} of vitamin A from the fruit flesh. Other important values (Table 2.1) include sugar levels of 7-16 % sucrose, small quantities of glucose and fructose, and abundant organic acids with the exception of ascorbic and citric acid (Taylor & Kwerepe, 1995; Weinert *et al.,* 1990; Jaenicke & Thiong'o, 2000; Hall *et al.,* 2002). It also have 83-91 % water, 1461 kJ/100 g of energy, 4-6 % of protein, 6-9 % of fibre, <10 % of fat and minerals including calcium, copper, iron, potassium, magnesium, sodium, phosphorus and zinc (Carr, 1957; Wehmeyer, 1966; Arnold *et al.,* 1985; Malaisse & Parent, 1985). For *Sclerocarya cafra* Viljoen *et al.* (2008) discovered that the fruit pulp contain two major volatile compounds important for odour and flavour of prospective products such as beer and cream. These were βcaryophyllene (91.3 %) and α-humulene (8.3 %). Their findings also report higher levels of Heptadecene (16.1 %); benzyl 4-methylpentanoate (8.8%), benzyl butyrate (6.7 %), (Z)-13-octadecenal (6.2 %) and cyclo-pentadecane (5.7 %) and that the major alcohol was (Z)-3-decen-1-ol (8.4 %) from fruit pulp and skin.

2.10.1.2. Kernel

The kernels have low moisture content and high fat, protein and mineral contents. They have 27-30 % protein, 2.02 % citric acid, malic acid, sugar, phosphorus, magnesium, copper, zinc, thiamine and nicotinic acid. The essential amino acid content of marula nut has been likened to human milk and whole hen's eggs (Weinert *et al.,* 1990). But it has low levels of lysine relative to other nuts making it a poor supplement of cereals diets (Hall *et al.,* 2002). Levels are also low for alamine, aspartic acid, leucine, phenylalanine, praline, and tyrosine but are rich in glutamic acid (0.24 g g^{-1} of protein) and arginine (Busson, 1965, Burger *et al.,* 1987).

Table 2.1: Nutritional composition of marula flesh from various countries

	Tanzania	Botswana	Zimbabwe	Senegal	DRC
DM (%)	14.88	15	14	-	17
Protein (%)	3.31	3.3	-	6.9	4.2
Carbohydrate (%)	88.39	80	-	68.5	70
Fat (%)	0.41	2.7	-	6.6	10.1
Fibre (%)	1.87	8	-	9.2	9.1
Ash (%)	6.03	6	-	8.8	6.6
Mg (mg/100g)	151.0	25.3	-	400	-
Na (mg/100g)	54.7	2.24	-	-	-
Ca (mg/100g)	11.8	20.1	-	800	-
K (mg/100g)	1524.6	317	-	2700	-
Zn (mg/100g)	0.4	0.1	-	-	-
Cu (mg/100g)	0.3	0.07	-	-	-
Fe (mg/100g)	3.5	0.5	-	-	40
P (mg/100g)	46.3	11.5	-	200	225
Vitamin C (mg/100g)	201.2	193	179		68
Vitamin A (mg/100g)	6.5	-	-	-	-

Source: Hall *et al.,* 2002; Masambu, *unpub M Sc thesis, 2004*

2.10.2. Properties of processed products

Oil, cosmetics, medicine and accoholic bevarages have been processed both at domestic and commercial scale. The extracted unrefined oil has a clear, light yellow color and is suitable for soap manufacture and edible use (Shone, 1979; Ogboge, 1992). The specific gravity and saponification value are comparable to those of olive oil. The iodine value is also near to that of olive oil but is low compared to sunflower oil (Weinert *et al.,* 1990). The oxidative stability of marula oil is thought to explain its successful utilisation in traditional meat preservation process (Shackleton *et al.*, 2002). The oil has low levels of vitamin E with 0.23 mg g^{-1} tocopherols (Burger *et al.,* 1987).

The oil content has a very good dietetic ratio of saturated to unsaturated fatty acids (Weinert *et al.,* 1990). The fatty acid profile is similar to that of olive oil but with stability that is ten times greater (Hall *et al.,* 2002). It has high mono-unsaturated content (C 18:1 – 66- 74 %) suggesting good oxidative stability. Kleiman *et al.* (2008) found an oil stability index (OSI) 37 h at 110 °C from subspecies *caffra* nuts. Its exceptional stability has been attributed to its fatty acid composition (high oleic acid content) as it has relatively low total tocopherol content (0.22 – 0.27 mg g-1 of oil) and low β-tocopherol (Burger *et al.,* 1987; Weinert *et al.,* 1990, Houghton, 1999; Eromosele & Paschal, 2003; Glew *et al.,* 2004). However, other studies have mentioned that some of the minor components in the oil may also be contributing to this important anti-oxidant property (Wynberg *et al.,* 2003).

Contrary to other locally produced beer and liquor, marula beer made by villagers in Swaziland is reported to have a quality almost comparable to commercial beer (Shongwe, 1996). It is nutritious and not as intoxicating as other local beers and liquor although its quality may vary depending on skills of the person making it and state of the fruits. Simulation of the local brewing procedure in a lab was done by Tiisekwa *et al.* (1996) to make beer which gave ethanol concentration of 6 %, which is in line with other commercial beer with high values of alcohol. The Amarula cream manufactured in South Africa has alcohol volume of 17 % and is traded worldwide. It has become the second largest seller in the cream liquor category after Bailey's Irish Cream, with particular success in Brazil. It is very popular and common throughout Africa, especially the south and east coast and recently it has attempted to break into the American market.

2.11. Summary

From this review it is evident that *Sclerocarya birrea* has been and continue to be useful to the economy and day to day life of people in sub Saharan Africa. However it appears that use of various marula products for various uses vary from place to place. While some communities are found to exploit at least some potential from the trees others do not use the tree at all. The reason for this are not published although they relate to differences in traditional knowledge, availability of market, culture and abundance of the species in the surrounding environment. Improved utilization and commercialization campaigns will need to take into account considerations for sustainability of uses and the resource itself because in those few areas where the tree appear to have been used for many years wild populations are reported to decline.

Research on *Sclerocarya birrea* is still limited because it has been conducted in few populations across its range, especially in the southern part of sub-Sahara Africa; and some research topics such as population studies are exceptionally scant. Reports on propagation methods are complex and somewhat contradictory. There is a need for harmonization and development of a cost effective and locally applicable technique. More such studies need to be done and should cover other areas including where subspecies *multifoliolata* is found. Tanzania is the centre of diversity for the species where all the three subspecies can be found with initial studies suggesting an exceptionally high genetic variation. Tanzanian populations in general; and subspecies *multifoliolata* in particular are the least studied. The three subspecies have never been studied concurrently before. Through this review it is seen that the populations in Tanzania are a unique opportunity for research, conservation and domestication (Kadu *et al.,* 2006). Therefore all the three can be studied at the same time to offer important information for comparison. Areas of research emphasis could be 1. evaluation of the resource base; 2. assessment of ecology, habitat, population structure, fruiting and fruit properties; 3. provenance trials; 4. phenology; 5. product development trials and innovations at local level; 6. propagation and silvicultural experiments; 7. post-harvest handling (including loses), storage, processing for domestic, national and international markets, value addition, agroindustralization/industrialization; 8. disease and pest control; 9. impact of deforestation on the quantity and quality of fruit; and 10. traditional knowledge held by different ethnic groups and associated with the species.

CHAPTER THREE: TRADITIONAL KNOWLEDGE ON *SCLEROCARYA BIRREA* POTENTIALS AND CONSTRAINTS FOR ITS IMPROVED MANAGEMENT AND UTILISATION IN TANZANIA

3.1 Background information

The longest history of humans interacting with their natural world is in Africa since it is believed the first man lived there. Despite development of domestication and settlement from 10,000 year ago, some rural African communities still hunt and gather wild food for subsistence consumption through various traditional methods. Even production of commodities for export into the global markets is still guided by some levels and forms of indigenous institutions (Maddox, 2006). Local people know so much about uses of forests such that Prance (1994) suggests that their traditional knowledge is investigated in the quest for identification of trees which can be domesticated for income generation. From the earliest life of mankind people everywhere had to decide who can use what resources when, where and how. Such norms, rules and regulations that govern behavior are broadly defined as institutions (Campbell *et al.,* 2003) and are driven by traditional local knowledge which is a result of years of practical research, in most cases undocumented.

In Sub-Saharan Africa traditional knowledge is reported to be influenced by forces of colonialism, post independence and globalization notably through introduction of programs such as Structural Adjustment Programs (SAPs) and Poverty Reduction Strategy Papers (PRSPs) (Kowero, 2003; Kajembe *et al.,* 2003). Through these programs initiatives to change management and power relations over forests have been introduced. These interventions seem to recognize and empower traditional management systems but at the same time lead to some form of formalization and integration with the conventional scientific knowledge of management. In many cases, parallel hierarchies of traditional leadership, local government, line department-sponsored committees, NGOs and donors exist often with unclear or overlapping jurisdictions and mandates in resource management in the end leading to institutional conflict and struggles for power (Kowero *et al.,* 2003).

Understanding traditional knowledge is essential to understand local realities of farmers and can be critical for the success or failure of improved management of forest resources (WinklerPins and Sandor, 2003). A modern science expands its knowledge and continues to draw from the important resource of local indigenous people (Brooks and McLachlan, 2008). According to Araya *et al.* (2006), indigenous people keep on transferring innovative type of information from generation to generation. Indigenous knowledge is significant for the improvement of the forestry sector (Saville and Upadhaya, 2006). Analyses of vegetation structure and ecosystem dynamics alone cannot serve to provide enough information about species and how they might be domesticated and utilized; incorporation of indigenous knowledge held by local practitioners is very important (Sinclair *et al.,* 1995). Rural communities in Tanzania, as is many other countries in Africa, have for many years depended on indigenous trees from the wild mainly for various uses. They have used trees and shrubs for browse, fodder, shade, living fences, windbreaks, fuelwood, poles, gums, resins, fruits, food and medicine (Milimo *et al.,* 1994).

Awareness of the neglect of indigenous trees was brought into attention about three decades ago. Leakey & Newton (1994) insisted the need for woody plant revolution to take over where green revolution left off after realizing that the resources so important to local people are diminishing and commercially ignored despite their potential. Many tropical trees, with direct use value to mankind, have been selected by generations of local people in various tropical countries and have been part of their traditional knowledge and institutions for food supply and farming systems (Okafor & Lamb, 1994, Waterman, 1994).

Ethnobotanical studies identified about 50 species used by local people in Tanzania, Malawi, Zambia and Malawi (Maghembe *et al.,* 1994) of which *Sclerocarya birrea* was one of them. A decade later Teklehaimanot (2005) conducted further surveys and found that *Sclerocarya birrea* is regarded as the most preferred species for development in Tanzania. Indigenous knowledge associated with the use of *Sclerocarya birrea* in Tanzania has never been assessed. It is only in Tanzania the three subspecies of the tree, namely *birrea, caffra* and *multifoliolata*, are found, creating a unique opportunity to compare the way they are managed and utilized by local communities. Usually the local knowledge centers around types and means of uses, population biology, phenology and propagation of tree resources.

Although information related to *Sclerocarya birrea* exist, especially from locations outside Tanzania; it remains evident that traditional knowledge associated with the species varies from one place to another (DFID, 2003). Global changes are said to have imparted a significant impact on cultures and consequently the ways of life of people in rural areas. This in turn makes perpetuation and conservation of traditional knowledge on uses of resources to erode, and current generation is said to know little about traditional knowledge compared to past generations (Huntington, 2000). The knowledge about uses of *Sclerocarya birrea* for various purposes is old, and current knowledge maybe different (AFREA, undated) and it neither cover subspecies *multifoliolata* nor compares the three subspecies. The present research was, therefore, conducted with the aim of eliciting and comparing indigenous knowledge about the three subspecies of *Sclerocarya birrea* from local communities in Tanzania.

3.2 Objectives

The main objective of the present research was to collect and analyse traditional knowledge and local constraints and opportunities towards improved management and use of *Sclerocarya birrea* in Tanzania.

3.2.1. Specific Objectives

- To acquire, document and evaluate local people's use and management of *Sclerocarya birrea*;
- To assess the potential for domestication of *Sclerocarya birrea* as an agroforestry tree;
- To understand local people's criteria for selection of plus trees;
- To evaluate institutional opportunities and constraints for domestication of *Sclerocarya birrea*;

3.2.2. Research Questions

- Do local people possess knowledge on the use and management of *Sclerocarya*?
- Does the existing land ownership and management styles provide suitable opportunities for domestication of *Sclerocarya*?
- Do local people possess criteria for plus tree selection?

- Are there any institutional barriers and/or potentials in domestication of *S. birrea*?

3.3. Materials and methods

3.3.1. Study villages and sampling

Data was collected from three regions located in different zones in Tanzania. From each region one village located in an area where one of the subspecies of *Sclerocarya birrea* occurs naturally was selected for this study. The villages were Holili in Rombo district, Kilimanjaro region in northern Tanzania; Kiegea in Morogoro district, Morogoro region in east-central Tanzania and Malinzanga in Iringa district, Iringa region in southern Tanzania. By road, the distance between Holili and Kiegea is approximately 600 km; between Holili and Malinzanga approximately 1100 km and between Kiegea and Malinzanga approximately 500 km. The sites were selected in such a way that each covered one of the three subspecies of *Sclerocarya birrea*. Subspecies *birrea* was found in the northern part of the country (Holili Village); *Caffra* in the east-central region of the country *Multifoliolata* (Kiegea Village) and in the southern region of the country (Malinzanga Village).

Stratified Simple Random Sampling was used to obtain households that were involved in questionnaire and Participatory Rural Appraisal (PRA) surveys. At each village 20% or at least 100 households were selected for questionnaire surveys. Twenty people from each village were involved in PRAexercises. Random numbers were used to select household heads for participation in questionnaire interviews and PRA. Stratification was done to try to strike a balance between sex, gender and social status (wealth) classes of respondents. Wealth classification according to villagers was used to rank social status of households/villagers based on size of farms, number of livestock, type of house and ability to pay school fees to children (Appendix I).

3.3.2. Description of the sampled households in the study villages

A total of 323 individuals were interviewed from all the three villages i.e. 114 (Holili village), 106 (Kiegea village) and 103 (Malinzanga village). The representation of males and females in the survey was fairly equal especially in Malinzanga village where the percentage of males was a little less than females i.e. 49.5% males and 50.5%

females. There were no female headed households in Holili, but in Kiegea a little less than one third of the households were headed by females and in Malinzanga only less than 10% of the households were headed by females. The main economic activity was farming in all the villages but in Holili business activities was regarded by 10% of the families as the main income generating activity (Table 3.1).

Table 3.1: Basic information describing farmers in areas where *Sclerocarya birrea* grows in Tanzania

Region	Kilimanjaro	Morogoro	Iringa
District	Rombo	Morogoro	Iringa
Sampled Village	Holili	Kiegea	Malinzanga
Subspecies	*S. birrea*	*S. caffra*	*S. multifoliolata*
Number of respondents (N)	114	106	103
Age of interviewees (mean)	39	40	32
Sex of interviewees (%)			
Male	57.9	53.8	49.5
Female	42.1	46.2	50.5
Female heads of household (%)	0	28.30	8.74
Size of household (mean)	6.4	4.15	5.79
Farming experience (years)	33-50	20-43	10-30
Main economic activity (%)			
Farming	84.2	100	100
Business	10.5	0	0
Formal Employment	0	0	0
Unemployed/student	5.3	0	0
Education (%)			
Standard 7 level	79	88.6	91.3
Form 4 level	15.8	5.7	0
Form 6 level	0	0	0
College level	5.3	0	0
No education	0	5.7	8.7
Tribes (#)	4 (Chagga 63%)	11	5(Bena 55%)

A total of 18 different ethnic groups were involved in this survey. This is 15% of the estimated 120 ethnic groups in Tanzania. Over all Chaggas and Benas were more represented (Table 3.1). In Holili there were 4 different ethnic groups, Kiegea was the most diverse village with 11 different groups and Malinzanga had 5 groups. Chaggas dominated in Holili village while Benas dominated in Malinzanga. It is noteworthy here that people from different tribes have a unique knowledge and perception on use and management of resources, which is normally a reflection of their respective ethnicity (Mazzocchi, 2006). Therefore an area with many ethnic groups living together is expected to harbor a rich and diverse traditional knowledge and perception about use of biodiversity.

The age of respondents in this survey ranged from a minimum of 18 to a maximum of 65 years. The average age was 37 and the most dominant age group was between 30 to 50 years (over 65%); while the least dominant group were those above 60 years old representing 2.5% of the respondents. Mean age of farmers was not significantly different between Holili (39) and Kiegea (40) but in Malinzanga it was significantly different (32) from the other villages.

In Holili 79% had seven years (primary school), 15.8% had eleven years (secondary school-form 4) and 5.2% had thirteen years (college diploma) of education. In Kiegea, 88.6% and 5.7% of the representative population had seven and eleven years of education respectively; while 5.7% had never been to school. In Malinzanga 91.3% had seven years of education and the rest (8.7%) had never been to school. In Tanzania, it is expected that by finishing seven years of school one is no longer illiterate, because they can read and write Swahili. The estimated percentage of people above 15 years of age who can write and read Swahili in Tanzania is estimated at 69.4% (NBS, 2002).

Most of the respondents were full time farmers, i.e. 94.4% of all respondents, and specifically at each site, farming accounted for 84.2%, 100% and 100% of the population in Holili, Kiegea and Malinzanga respectively. Some of the farmers were engaged in additional income generating activities to supplement income from farming. These activities include rock brick carving in Holili (31.6%, plate 3.1), and food and local beer business at local clubs in Kiegea (25.8%) and Malinzanga (23.6%).

The average household size in this study was 5.5; however there were variations between the study villages. Mean household size in Holili, Kiegea and Malinzanga was 6.4, 4.15 and 5.79 respectively. The national average household size is 4.9 (NBS, 2002) and therefore household size in Holili and Malinzanga was on the higher side compared to the national average.

3.3.4. Data collection

Data on traditional knowledge was collected using PRA methods, direct observation and household questionnaire (Appendix II) to gather information on: (1) local peoples' use and management of selected trees, (2) the importance and/or potential of these species in household livelihoods, (3) challenges facing farmers in efforts for exploitation of *Sclerocarya birrea* for improvement of livelihood, and (4) local peoples' criteria for selection of good quality *Sclerocarya birrea* trees i.e. plus trees. Matrix, Pair-Wise Ranking and Problem Ranking PRA techniques were used.

3.3.5. Data analysis

Data obtained in PRA was organized, tabulated and where appropriate used to generate graphs/charts. Ambiguous information was incorporated into the questionnaire survey and observed directly in the field in order to get more clarification. Questionnaire data was coded and analyzed using SPSS 16 to generate summaries of the responses from the survey. The analysis generated tables, figures and charts which are presented and elaborated in the results section.

3.4. Results

3.4.1. Land assets and the implication to ownership and management of *Sclerocarya birrea*

The results for land ownership, size and management are summarized in table 3.2. Farmers acquired the land they hold through hiring (30%), purchase (24.1%), inheritance (22.6%) and bush clearance (17.6%). But at each village the proportion of ways in which people acquire land for farming was different. While in Holili hiring was (26.4%), inheritance (36.8%), purchasing (36.8%), forest encroachment (0%); and in Kiegea hiring (23.6%), inheritance (29.2%), purchasing (17.9%) and forest encroaching (29.3%); in Malinzanga hiring was 40.8%, none was inherited, 16.5 was through purchasing and forest encroachment accounted for 42.7%. This implies that there was a considerable amount of forest areas that were converted to new farmlands by the current generation in Kiegea and Malinzanga while in Holili land was largely inherited meaning it was converted from forest by at least the previous generation.

Farmers have land of various sizes ranging from less than 1 ha. to more than 76 ha. Average land size was 7.50±1.50 ha for Holili, 6.40±0.49 ha. for Kiegea and 8.50±1.30 ha. for Malinzanga. However those with big chunks of land were not able to farm all of them at a time due to lack of operating capital. More *Sclerocarya birrea* trees were retained by farmers with small land holdings than those with big chunks of land (figure 3.1). This is contrary to the common experience where people with small land are expected to remove trees so as to give way for perennial agricultural crops. Although it was not covered or mentioned by any respondent during this study, there are possibilities of improved crop performance when *Sclerocarya birrea* is incorporated in the agroforestry systems. Indeed in Kiegea where the abundance of *Sclerocarya birrea* on farms is the highest (Chapter 4), farmers regard organic fertilisation as the main method of soil improvement (Figure 3.2). However further tests are required to establish if at all *Sclerocarya birrea* has significant effects on yield of associated crops .

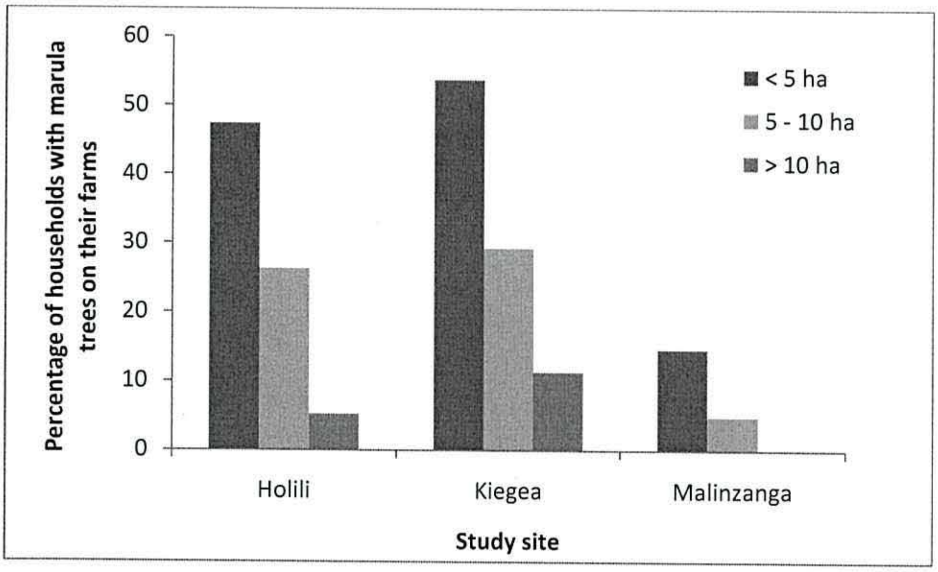


Figure 3.1: Retention of *Sclerocarya birrea* trees on farms in relation to land owned by households in the study villages

To be able to separate farming systems used by farmers; agroforestry, agropastoralism and crop rotation categories were used. Agroforestry here refers to farmers who cultivate a variety of crops in a mixture with tree species; agropastoralism refers to those practicing agroforestry but also raising livestock such as chicken, goat, pig and cattle. Crop rotation is the cultivation of similar or different types of crops on the same piece of land repeatedly during different seasons of the year or annually. There were three main types of farming systems throughout the study villages. In Holili 89.5% and 10.5% practiced agroforestry and agropastoralism respectively; no farmer was using crop rotation system. In Kiegea all farmers (100%) practiced agroforestry, none practiced agropastoralism or crop rotation while in Malinzanga 50.5%, 0% and 49.5% were practicing agroforestry, agropastoralism and *single*-crop rotation (mainly for rice) respectively.

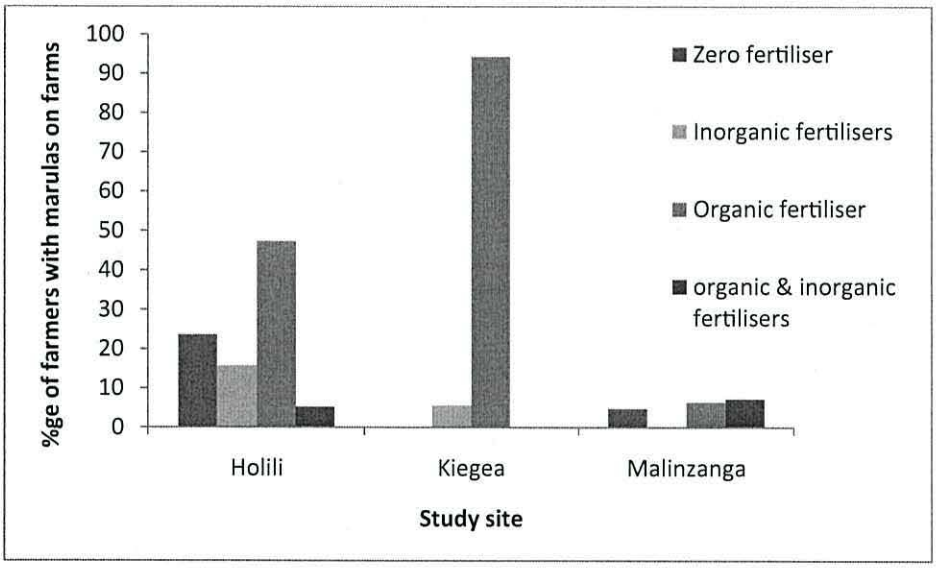


Figure 3.2: Percentage of farmers who retain *Sclerocarya birrea* on their farms under different categories of land and/or crop management

The results also indicated farmers use agro inputs differently (Table 3.2). In Holili 10.5% of farmers use inorganic fertilisers, 57.9% use organic manure, 26.3% don't use any additions to soil and 5.3% use a combination of organic and inorganic fertilisers. All the farmers in Kiegea use organic fertilisers as the only agro input for improving soil fertility. In Malinzanga 15.5% use inorganic fertilisers, none use organic fertiliser, 75.7% do not use fertiliser at all while 8.7% of them apply irrigation on their farms. Figure 3.2 shows that farmers who use inorganic fertilisers have less *Sclerocarya* trees on their farms compared to those who do not use inorganic fertilisation. 80% of respondents who use organic fertilisers alone have *Sclerocarya* trees on their farms while a little more than 10% of those who use inorganic fertilisers have the tree on their farms. As noted earlier this also shows that the trees might be having a positive effect on crop production to farmers; who would otherwise be unable to afford inorganic fertilisers which are actually expensive and harmful to the environment (Mandal *et al.*, 2007).

Table 3.2: Land tenure, use and management in areas where *Sclerocarya birrea* grows in Tanzania

Region	Kilimanjaro	Morogoro	Iringa
District	Rombo	Morogoro	Iringa
Sampled Village	Holili	Kiegea	Malinzanga
Subspecies	*S. birrea*	*S. caffra*	*S. multifoliolata*
Source of land (%)			
Hired	26.4	23.6	40.8
Inherited	36.8	29.2	0
Bought	36.8	17.9	16.5
Forest encroached	0	29.3	42.7
Land use system (%)			
Agroforestry	89.5	100	50.5
Agropastoralism	10.5	0	0
Crop rotation	0	0	49.5
Fertilisers (%)			
Inorganic	10.5	0	15.5
Organic	57.9	100	0
Inorganic and organic	5.3	0	0
None	26.3	0	75.7
Irrigated land	0	0	8.7

3.4.2. Yield of crops growing in association with *Sclerocarya birrea*

Information on the food crop component is an important land-use and biodiversity baseline data in agroforestry systems (Leakey, *undated*). It gives information on which crops farmers have selected and grown for years in these particular environments as well as the respective yields. For any effort intended to intensify domestication of *Sclerocarya birrea*; these crops which have traditionally occurred in the same environment will in most cases best suit the tree-crop interaction processes.

There were seven major crops raised by farmers throughout the villages where *Sclerocarya birrea* grows as shown in figure 3.3a-c. In Holili 90%, 5%, 90%, 58%, 74% and 31% of the households grows maize, sorghum, sunflower, beans, groundnuts and cassava respectively. In Kiegea 100%, 55%, 7%, 11% and 77% of farmers grow maize, sunflower, beans, groundnut and cassava respectively. In Malinzanga 76%, 33.0%, 24.3%, 91.3% and 80.6% of farmers grow maize, beans, groundnut, rice and cassava respectively. So there is a wide range of crops grown alongside *Sclerocarya birrea* trees in *'parkland agroforestry system'* in Tanzania. Maize is the main crop grown and regarded as main food crop in all villages. Preference for other crops varies between the villages as indicated by the percentage of farmers growing the crops. Sunflower, beans and groundnuts are grown by a majority of farmers in Holili while in Kiegea preference is on cassava and sunflower. Malinzanga is the only village which grown rice in large quantity and the only village where farmers practice irrigation.

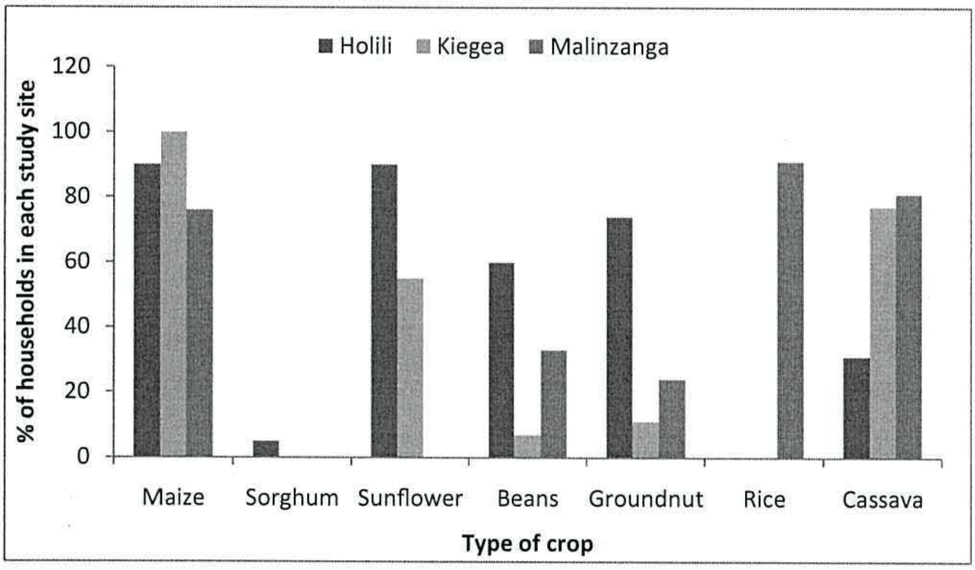


Figure 3.3: Percentage of households cultivating various crops in Holili; Kiegea and Malinzanga

Yield of crops was different between villages. In this survey yield is given in amount of a particular crop per household and not per hectare basis because farmers tend to remember what they produced on their farms. They do not necessarily cultivate all the land they posses and they don't measure the land cultivated each season, it is complicated to come up with data of yield per hectare. For generalization purposes the figures may be manipulated using the mean size of land owned by household at each village although this creates a big room for error in the estimations. To get more accurate data on yield per hectare in these areas participatory research where farmers and researchers will be involved from land preparation to harvesting is suggested. Household mean crop yield (Table 3.3) in 100kg bags (number of bags in bracket against respective crop) was as follows: *A.* Holili - maize (10.00±2.0), sorghum (0.11±0.04), sunflower (4.26±0.42), beans (0.80±0.11), groundnuts (2.74±0.36) and cassava (2.93±0.58); *B.* Kiegea - maize (5.60±0.44), sunflower (4.07±0.45), beans (0.06±0.02), groundnuts (0.11±0.04) and cassava (10.15±0.81); and *C.* Malinzanga - maize (24.53±2.91), beans (2.45±0.41), groundnuts (2.64±0.79), rice (44.11±5.26) and cassava (8.44±0.63). The most cultivated crops (in terms of area cultivated) and thus high yields were maize and cassava.

Average household consumption of the main/staple food; which in most cases is maize per year is 6 bags (figure 3.4). The average prices of crops for a 100kg bag of crop was as follows:- maize = Tshs 25,000, sorghum = Tshs 10,000, sunflower = Tshs 30,000, beans = Tshs 70,000, groundnuts = Tshs 80,000, rice = Tshs 35,000 and cassava = Tshs 4000. In a very general way, assuming that more than half of the maize and all other crops are available for sale, a farmer would be earning roughly a gross income of Tshs 600,000 per year. This is equivalent to just over a US dollar per day and therefore introduction of new income generation activities such as domestication and commercialization of *Sclerocarya birrea* can contribute to livelihood improvement of farmers.

Table 3.3: Mean crop production per household in the study villages

Crop	Yield in 100kg bags		
	Holili	Kiegea	Malinzanga
Maize	10.00±2.0	5.60±0.44	24.53±2.91
Sorghum	0.11±0.04	0	0
Sunflower	4.26±0.42	4.07±0.45	0
Beans	0.80±0.11	0.06±0.02	2.45±0.41
Groundnuts	2.74±0.36	0.11±0.04	2.64±0.79
Rice	0	0	44.11±5.26
Cassava	2.93±0.58	10.15±0.81	8.44±0.63

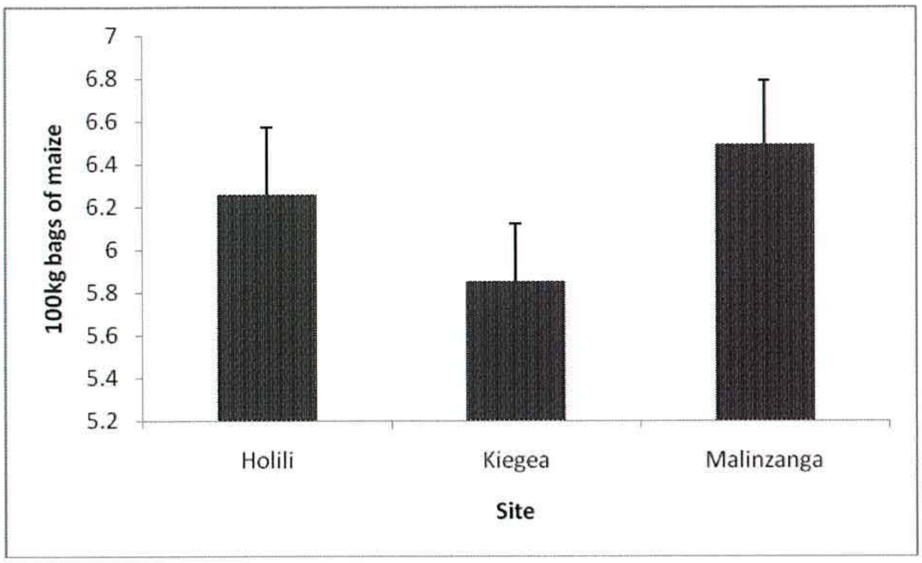


Figure 3 4: Average household consumption of the main food crop in 100 kilogram bags per year for people in areas where *Sclerocarya birrea* occur in Tanzania

3.4.2. Potentials of available infrastructure in marketing of *Sclerocarya birrea*

Market location, road conditions, means of transportation and different media-communication can influence marketing of farm products especially *Sclerocarya birrea* whose fruits are the main products and are perishable (Yamano and Kijima, 2009). In Holili and Malinzanga 21.1% & 8.7% of farmers sell their crops at local markets close to their homes (<3km) while 21.1% and 7.8% of farmers sell their crops to markets far from their homes (up to 15km) respectively. The rest i.e. 57.9% (Holili), 100% (Kiegea) and 83.5% (Malinzanga) sell their crops to middlemen at the farm gate (figure 3.5 a-c).

a b

Plate 3. 1: (a) Poor road in Holili village; (b) Good road in Malinzanga village

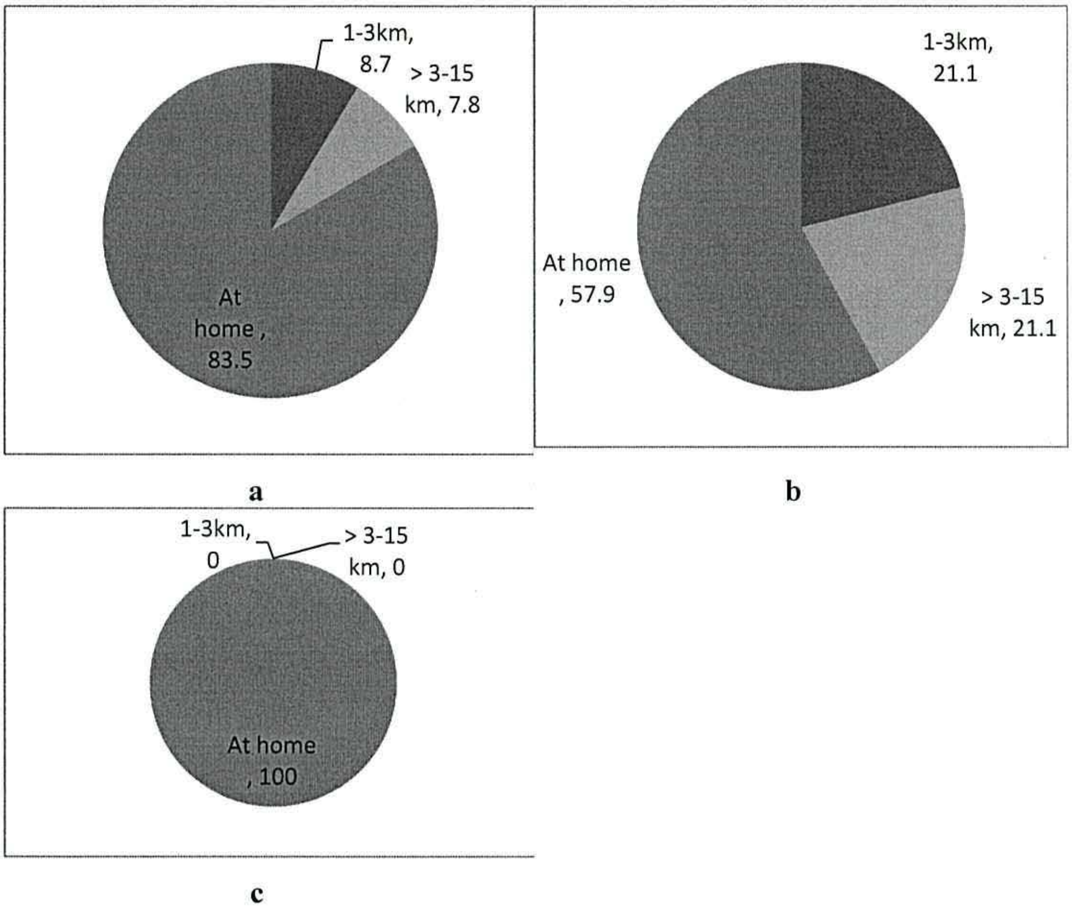


Figure 3 5: Market location (%) in (a) Malinzanga; (b) Holili (c) Kiegea

Village road condition in rural areas tends to be impassable during some times of the year but even throughout the year for some places. In the study areas all farmers (100%) in Kiegea and Malinzanga thought their roads are in good condition and therefore passable by van almost throughout the year, but in Holili 89.5% of farmers regard their roads as poor. Direct observation during field visits confirmed the results from interviews (Plate 3.1a-b).

The main means of crop transportation to market or middlemen was tractor, bicycle and on-foot (Table 3.4). Farmers in Holili use foot means (47.4%), bicycle (31.6%) and vehicle (21%). In Kiegea farmers use foot (36.8%) and bicycle (63.2%) as the only means of transport. In Malinzanga the main means of transport is foot (83.5%) while a few use tractor (8.7%) and van (7.8%). Crops were sold in their raw form e.g. maize are sold before they are processed to flour, rice sold with its husks, cassava sold without peeling, etc.

Table 3.4: Means of crop transportation in percentage by farmers in the villages where *Sclerocarya birrea* grows in Tanzania

Means of transport	Holili village (%)	Kiegea village (%)	Malinzanga village (%)
Foot	47.4	36.8	63.5
Bicycle	31.6	63.2	20
Van	21.0	0	7.8
Tractor	0	0	8.7

3.4.3. Institutions, opportunities and constraints associated with management and use of *Sclerocarya birrea*

Information on ownership and institutional issues surrounding the use and management of *Sclerocarya birrea* (also applicable to most of the other trees) is given in Table 3.5. Ownership of *Sclerocarya birrea* tree resources on farm and in the wild populations was either private or village government/public although the distinction is unclear to some villagers. In Holili both on farm and wild *Sclerocarya* trees were 100% owned by individual people. In Kiegea 77.4% declares that the trees on their farms are under their ownership while 22.6% farmers claim that although the trees belong to them, they don't have right over their uses. Trees on forest land are perceived to belong to the government although some form of public ownership was observed because of free grazing, charcoal making and fuelwood collection.

In Malinzanga all (100%) claims they don't have user-rights over *Sclerocarya birrea* trees on their farms and that 100% of the trees in the wild are under the jurisdiction of a selected village environmental committee. The committee safeguards the forest against encroachers and issues permits to farmers who have applied for collection of goods like fuelwood and construction materials. In the study sites bylaws on management and use of trees exist. They include obtaining permits to harvest whole or part of trees, forest protection against fire, controlled grazing, reserving land for forest carbon sequestration and customary laws.

Table 3.5: Potentials and barriers for improved use and management of *Sclerocarya birrea* in the study villages

Region	Kilimanjaro	Morogoro	Iringa
District	Rombo	Morogoro	Iringa
Village	Holili	Kiegea	Malinzanga
Subspecies	*S. birrea*	*S. caffra*	*S. multifoliolata*
Ownership of trees on farm (%)			
Farmer	100	77.4	0
Farmer with no user-right	0	22.6	100
Ownership of trees in forests (%)			
Farmer	100**	0	0
Government/public	0	100	0
Village Environmental Committee	0	0	100
Knowledge/use of by laws (%)			
Customary laws	94.7	75.5	83.5
Government bylaws	5.3	0	0
Not aware	0	14.5	16.5
Aim of laws	conservation	conservation	conservation
Shortfalls of laws	-	no user-right	no user-right
Availability of forest extension services (%)	15.8	0	74.8
Trees useful for livelihood	Environmental services (100%)	Environmental services (100%)	Environmental goods & services (91.3%)
Barriers to benefit from non-timber products	Institutional & low tree stock	Institutional	Institutional
Perceived solution	Capacity building	Capacity building	Capacity building

The results in Table 3.5 present the knowledge and use of bylaws in the study villages. Farmers are aware that there are rules and regulations in relation to management and use of *Sclerocarya birrea* resources. The understanding of the regulations is not uniform. 100%, 75.5% and 83.5% of farmers in Holili, Kiegea and Malinzanga knows at least that there are by laws made by the village government, or by elders or by both for the management of forest resources. There are those who are completely unaware of existence of any bylaws; 14.5% in Kiegea and 16.5% in Malinzanga. Farmers perceive the strengths of the bylaws as important for conservation because they help protect the forests against wild fires, encroachment, destructive harvesting, overgrazing etc.

However the bylaw which denies user rights of on farm trees is not welcomed by many farmers to an extent that 82% of farmers in Malinzanga would prefer uprooting regenerating *Sclerocarya* seedlings because when they mature they won't belong to them even if they are on their farmlands.

Majority of farmers in the villages do not have access to sufficient and appropriate management and conservation extension services pertaining to *Sclerocarya birrea* and other trees. About 15.8% of respondents in Holili and 74.8% of respondents in Malinzanga have benefited from some form of training on management of natural resources done occasionally by NGOs or researchers in specific participatory projects. These NGOs and researchers would come to these villages very occasionally and work with a few farmers and therefore majority of farmers cannot benefit from them. Therefore although they have traditional knowledge on uses of various local trees, they lack silviculture and entrepreneurship knowledge of both local and exotic trees. Such knowledge includes propagation, tending, processing and market information and requirement for various trees.

3.4.4 Challenges in management of *Sclerocarya birrea*

Various challenges towards successful domestication campaigns for *Sclerocarya birrea* in the study villages are shown in Table 3.6. Lack of knowledge on propagation skills, low levels of awareness of potential benefits from trees, lack of value and market information for tree resources like *Sclerocarya birrea* were the most common barriers facing farmers towards their ambitions for domestication. Other problems include wild fires, overgrazing, drought, theft, pests, diseases and lack of extension services.

In Malinzanga respondents indicated lack ownership rights as disincentive to retain or plant *Sclerocarya birrea* on their farms. This was among the potential barriers to domestication of the species and needs to be taken into consideration in any interventions for improved management. Some respondents also perceive trees as unsuitable in their farms because they create habitat and corridor for destructive wildlife especially monkeys; therefore they would rather cut down trees to avoid wildlife conflict.

Table 3.6: Challenges affecting management and utilization of forest resources in areas where *Sclerocarya birrea* grows in Tanzania

Problem	Applicable problem and its rank by subspecies		
	birrea	*caffra*	*multifoliolata*
Wild fires	0	4	0
Drought	3	3	7
Deforestation	0	8	8
Pests (termites) & diseases	4	7	0
Propagation	1	2	1
Wildlife conflict	0	6	3
Overgrazing	0	9	2
Market knowledge	2	1	2
Lack of Extension services	0	5	6
Ownership	0	10	4

(1 = most serious problem; 0 = not mentioned as a problem)

3.4.5. Local knowledge on *Sclerocarya birrea*

3.4.5.1 Tree preference

Villagers were asked to list 10 most useful trees in their villages. Matrix scores for the 10 best trees against their uses were used in identifying and valuing the useful trees scoring them from 0 to 10 i.e. 0 the least score and 10 the highest. Out of the ten most important tree species that are found in each village, *Sclerocarya birrea* received least score in Kiegea, sixth ranked in Holili and second ranked in Malinzanga when the species was evaluated against various important uses including timber, fuelwood, medicine, and shade (Table 3.7). However, when *Sclerocarya birrea* was compared with other fruit bearing indigenous as well as exotic tree species subspecies *birrea* was ranked ahead of *Mangifera indica* and *Adansonia digitata* in Holili. Subspecies *caffra* was ranked behind *M. indica* and *Anacardium occidentale* in Kiegea while subspecies *multifoliolata* was ranked behind *Tamarindus indica* and but ahead of *M. indica* and *A. digitata* in Malinzanga (Table 3.8). The percentage weight scored by each species in each village is given in figure 3.6 to 3.11.

Table 3.7: Ten most useful trees based on farmers ranking for each study site

Holili	Kiegea	Malinzanga	Rank
Gravelia robusta	*Dalbergia melanoxylon*	*Tamarindus indica*	1st
Acacia nilotica	*Mangifera indica*	*S. birrea subsp. Multifoliolata*	2nd
Eucalyptus	*Anacardium occidentale*	*Pterocarpus angolensis*	3rd
Azadirachta indica	*Rhus natalensis*	*Afzelia quanzinsis*	4th
Dalbegia Melanoxylon	*Tectona grandis*	*Lonchocarpus capassa*	5th
S. birrea subsp. birrea	*Combretum zeyheri*	*Ficus thoningii*	6th
Albizia amara	*Combretum molle*	*Mangifera indica*	7th
Rauvolfia cafra	*Xeroderris stuhmanii*	*Adanansonia digitata*	8th
Mangifera indica	*S. birrea subsp. Caffra*	*Azadirachta indica*	9th
Adanansonia digitata	*Burkea africana*	*Terminalia sericea*	10th

Table 3.8: Ranking of the subspecies of *Sclerocarya birrea* with other fruit trees in the study villages based on multiple uses

Holili	Kiegea	Malinzanga	Rank
S. birrea subsp. birrea	*Mangifera indica*	*Tamarindus indica*	1st
Mangifera indica	*Anacardium occidentale*	*S. birrea subsp. Multifoliolata*	2nd
Adanansonia digitata	*S. birrea subsp. Caffra*	*Ficus thoningii*	3rd
		Mangifera indica	4th
		Adanansonia digitata	5th

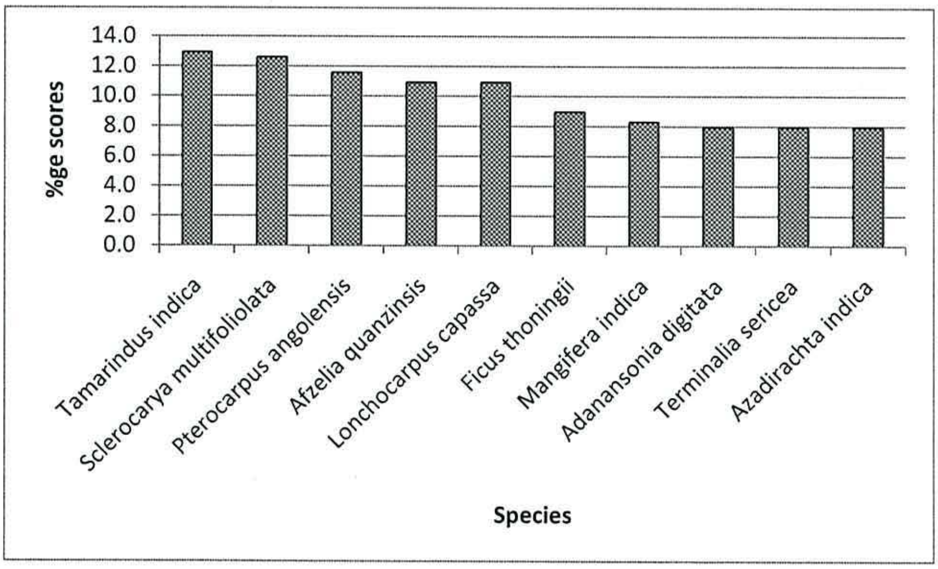


Figure 3.6: Percentage matrix scores of important species in Malinzanga village

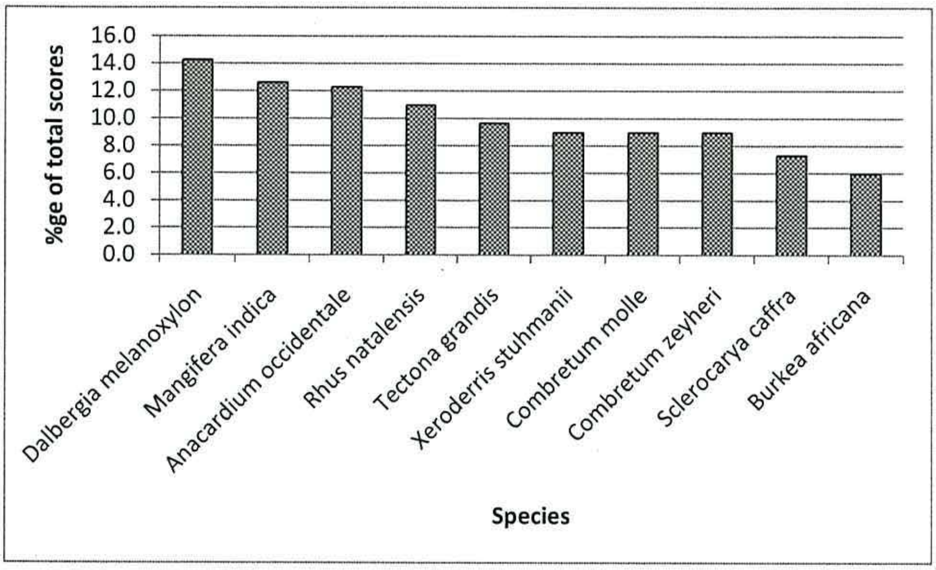


Figure 3.7: Percentage matrix scores of important species in Kiegea village

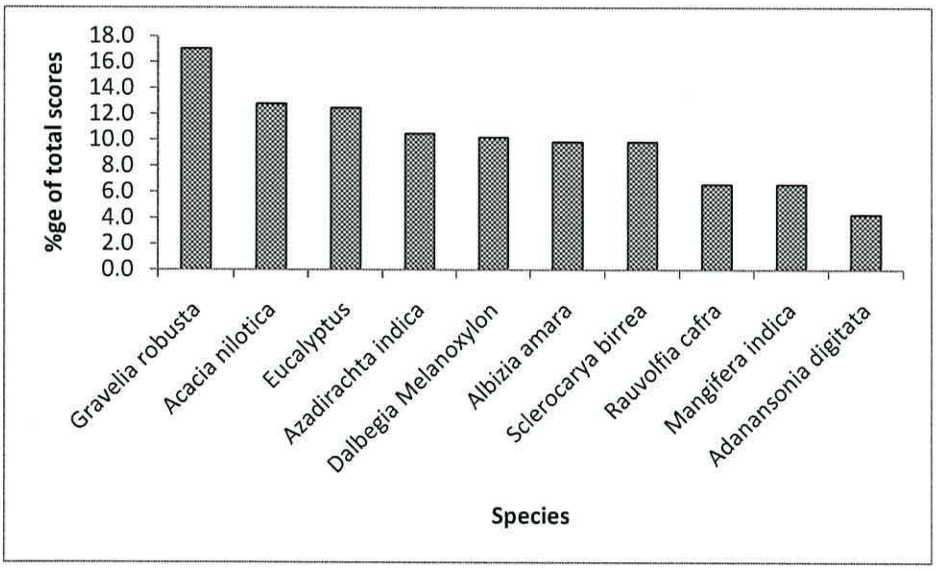


Figure 3.8: Percentage matrix scores of important species in Holili village

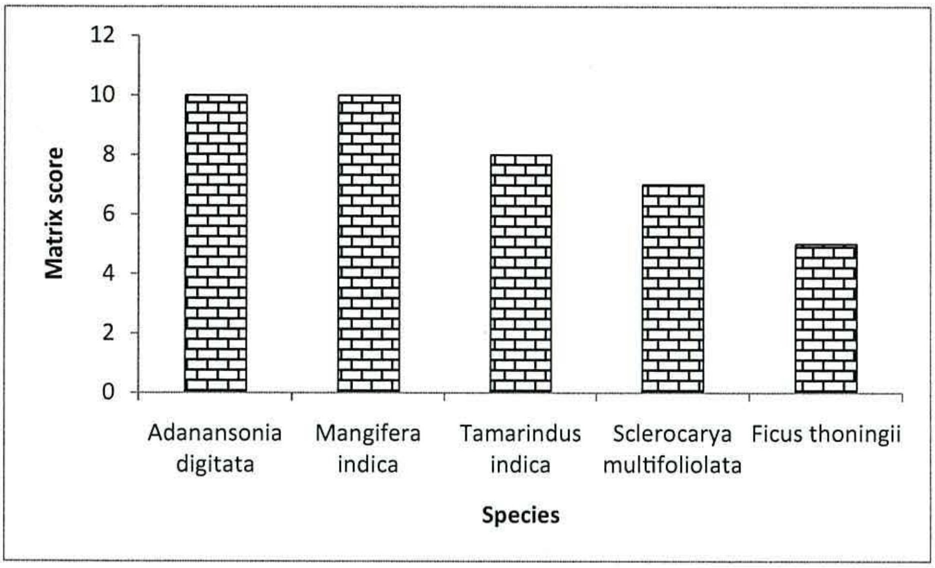


Figure 3.9: Comparison of *Sclerocarya birrea* with other fruit trees in Malinzanga village

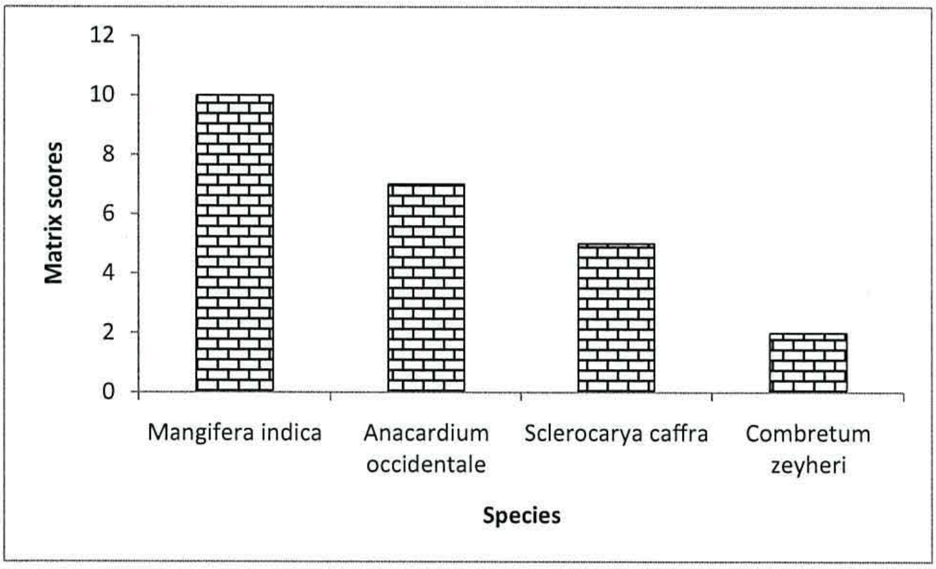


Figure 3.10: Comparison of *Sclerocarya birrea* with other fruit trees in Kiegea village

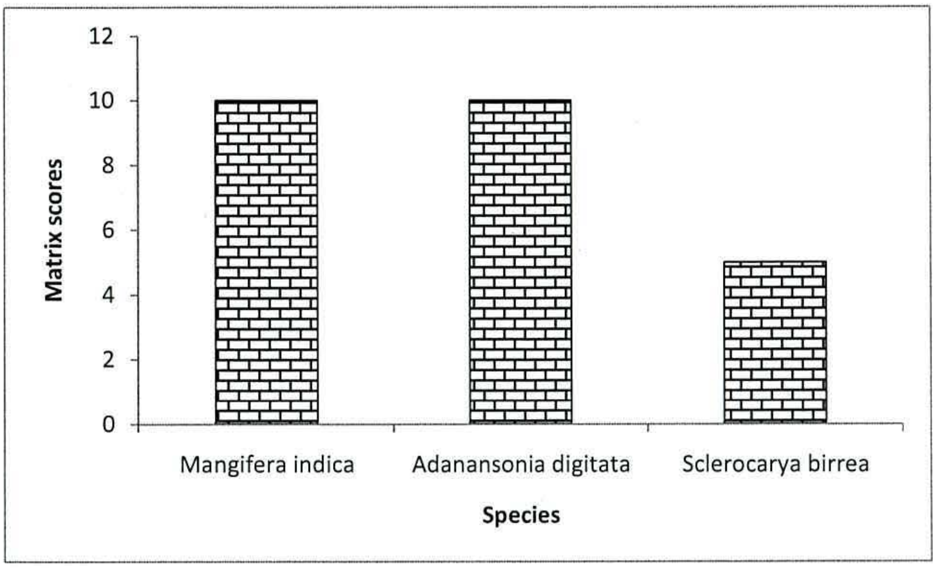


Figure 3.11: Comparison of *Sclerocarya birrea* with other fruit trees in Holili village

3.4.5.2. Important uses of *Sclerocarya birrea*

Uses of *Sclerocarya birrea* are given in Table 3.9. The most important use for subspecies *birrea* was shade (1^{st}) and fodder (2^{nd}); for subspecies *caffra,* shade (1^{st}), traditional chairs (2^{nd}) and mortars (3^{rd}); and subspecies *multifoliolata* was medicine (1^{st}), traditional chairs (2^{nd}) and mortars (3^{rd}). Shade which emerged as among the most important use was reflected by the level of *Sclerocarya birrea* dominance within the vegetation compared to other species both on farms and in the wild. The shade is used by farmers taking a rest during farming and while watching grazing livestock. It is also used during meetings or at home where the tree was observed retained on household yards (Plate 3.2).

Plate 3. 2: A *Sclerocarya birrea* subspecies *caffra* retained and traditionally protected against pests using ash in front of a farmers' house in Kiegea Village

There was knowledge on many uses (8 uses) for subspecies *multifoliolata* than the other two subspecies (5 for subspecies *birrea* & 4 for subspecies *caffra*). Key informants interviews revealed that for medicinal uses, subspecies *multifoliolata* is used to treat gonorrhea (boiling the bark); diarrhea (boiling the bark, pounding and drying of leaves); diabetes (boil leaves and the obtained liquid mixed with honey); and malaria (a mixture of its leaves with those of *Mangifera indica* boiled together).

Relative importance of various uses of the subspecies of *Sclerocarya birrea* from the point of view of respondents as percentage scores are shown in figure 3.12. Uses with score of importance above 10% are timber (11%), medicine (13 %), tool making (21 %), fruits (18 %), fodder (13 %) and shade (11 %) for subspecies *multifoliolata*. Subspecies *multifoliolata* was the only one whose wood was found to be suitable for fuelwood and timber. Information about wood chemical and physical properties, which is important for fuelwood and timber, available in literature is for subspecies *caffra* and *birrea* (Hall *et al.,* 2002). The subspecies are reported to have light, soft and low strength properties. It will therefore be interesting to assess the wood properties of subspecies *multifoliolata* to find out any relationship with its unique use for timber and fuelwood as compared to its sister subspecies that were reported unsuitable for such uses due to poor wood quality. For subspecies *caffra* the uses were environmental conservation (13 %) , tools (14 %), fruits (23 %), fodder (14 %) and shade (27 %) For subspecies *birrea* medicine, tools and fruits all scored 19% while shade was the most important use with a score of importance of 29 %.

Table 3.9: Uses of *Sclerocarya birrea* subspecies in Tanzania

Uses	S. birrea	S. caffra	S. multifoliolata
Medicine	3	4	1
Traditional chairs	none	2	2
Mortars	none	3	3
Fruits	5	none	5
Fodder	2	none	7
Cooking oil	none	none	8
Snack (nuts)	4	none	4
Timber	none	none	6
Shade	1	1	none

1 = the most important use

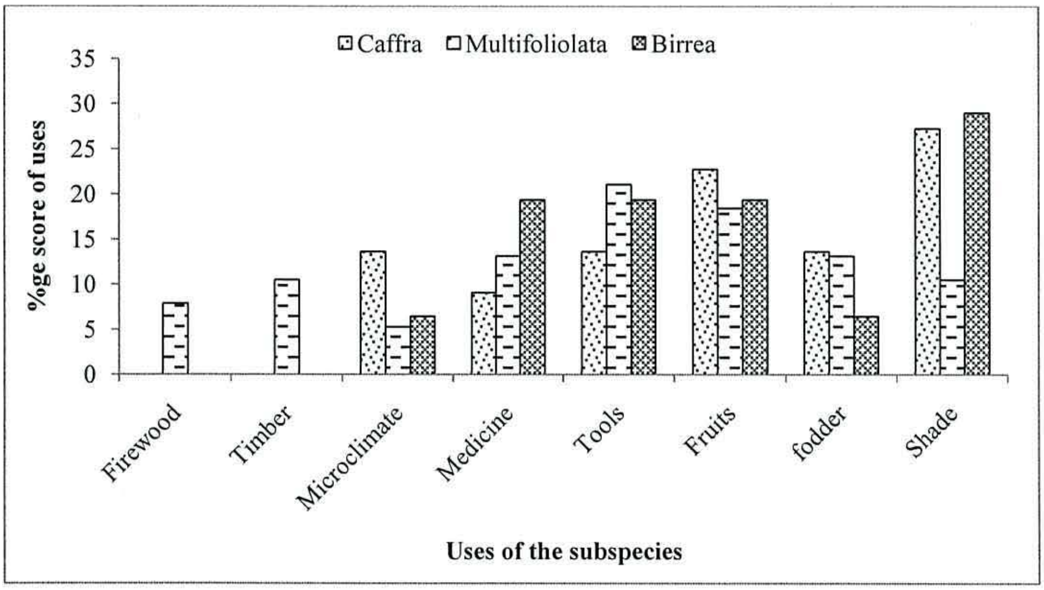


Figure 3.12: Uses of the three subspecies of *Sclerocarya birrea*

3.4.5.3 Local use and means for eating *Sclerocarya birrea* fruits

The fruits of *Sclerocarya birrea* become ripe after abscising from the tree and staying on the ground for up to a week (Hall *et al.,* 2002). Key informant interviews showed that fruits are picked from under *Sclerocarya* trees when they are ripe by observing if their color has turned to yellow or yellowish-green and are soft when pressed. In most cases because they are eaten on the spot, the fruits are not washed but just wiped off any observed dirt using hands or clothes. Gently pressing, people hold and roll the fruit between the hands to separate the juice from the fibers; then bite the skin to make a small opening through which they suck the sweet juice. Others peel the fruit using finger nails or teeth before squeezing the fruits in their mouth and spitting out the nut after the juice and flesh are swallowed.

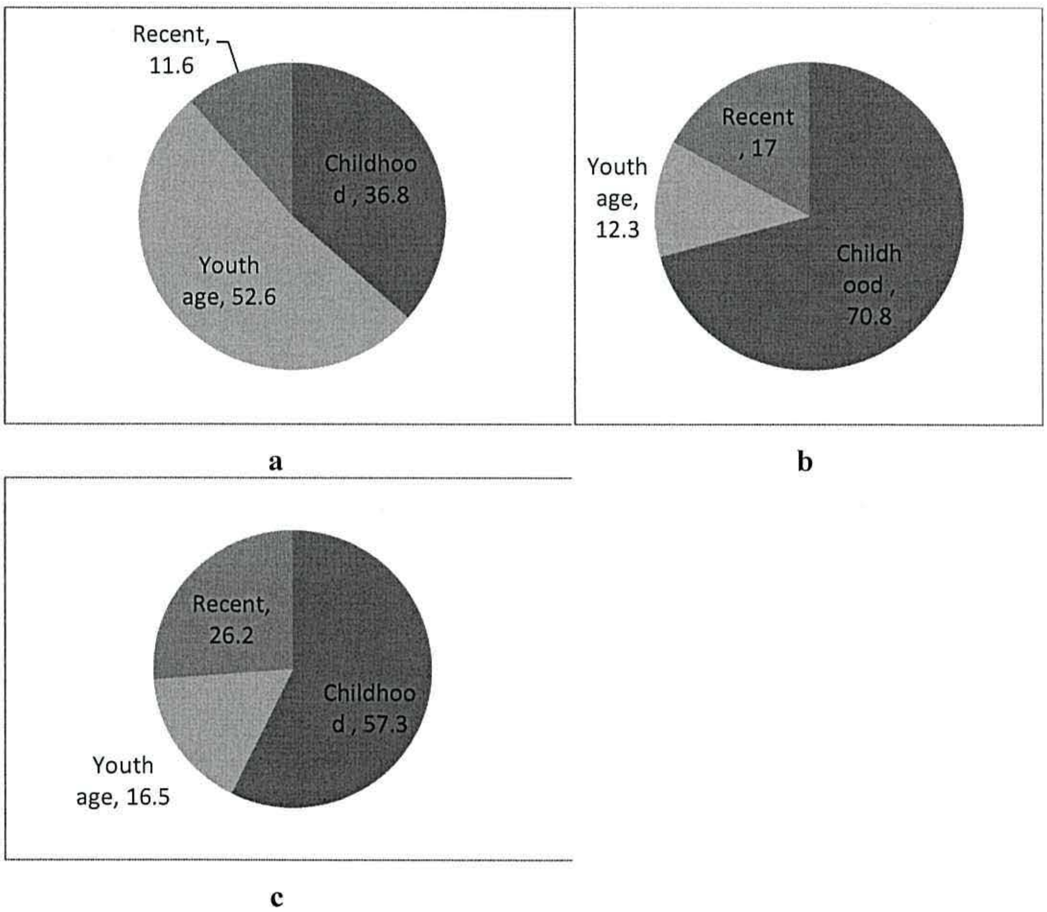


Figure 3.13: History of knowledge of marula trees in % of villagers in (a) Holili; (b) Kiegea; (c) Malinzanga

Consumption of the fruits of *Sclerocarya birrea* as food during different ages of respondents is presented in figure 3.13. In Holili 36.8%, 52.6% and 11.6% have eaten

Sclerocarya during childhood, youth age and adulthood respectively. In Kiegea 70.8%, 23.3% and 17% ate the fruit during childhood, youth age and adulthood respectively. In Malinzanga 57.3%, 16.5% and 26.2% of farmers ate marula during childhood, youth age and adulthood respectively. Most of the farmers, who eat the fruit after childhood, claimed to do so occasionally while collecting fodder or fuelwood in the forests.

Many people are not always ready to admit eating of wild fruits because they feel it downgrade their status as wild fruits are regarded as for the poor people (Rufo *et al.*, 2002). In this study all adults with no education said they don't eat marula fruits while there was a good proportion of adults, (75 % of those with secondary education), who said they eat the fruit (Figure 3.14). This does not necessarily mean that people who had more education eat marula fruits more than those with less or no education, it may instead be because educated respondents are more knowledgeable and have more confidence in their choices and equally so in revealing them.

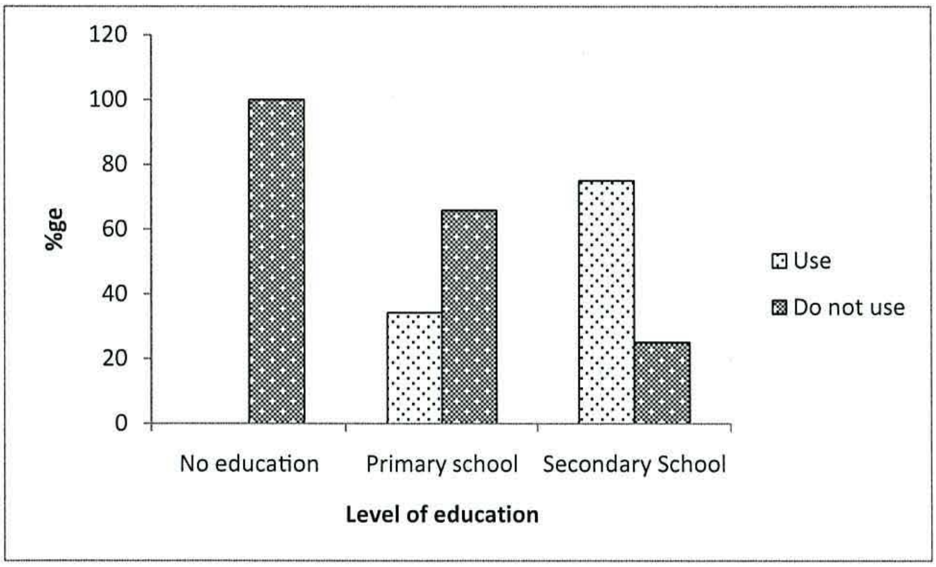


Figure 3.14: Percentage of respondents who uses *Sclerocarya birrea* fruits in relation to their level of education

Analysis of using marula fruits for food based on gender revealed that those who declared to be eating the fruits were mostly men. There were 48 % of men and 20 % of women who eat the fruits of marula throughout the study villages (Figure 3.15). This is contrary to obvious expectation of women to be eating more of the fruits because of their more interaction with nature during farming and collection of firewood (Goode, 1989). Because men are responsible for walking livestock during grazing and most of them indicated eating the fruit most during childhood then it may be the reason for this difference. The exact reason for the shift in consumption of wild food resources by gender and age are not well given and therefore more research is needed. Agea *et al* (2011) also report a balanced consumption of wild fruits in terms of gender and age in Uganda.

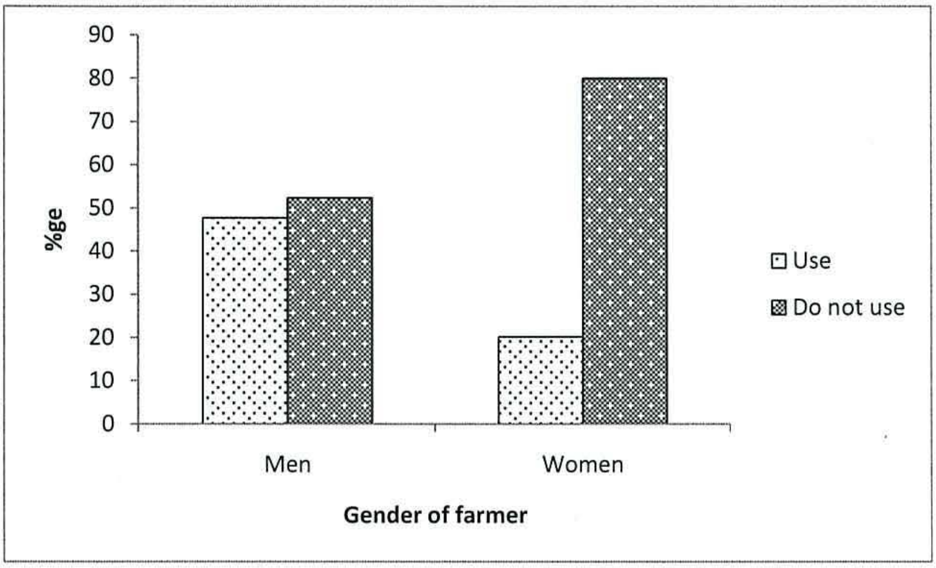


Figure 3.15: Proportion of usage of *Sclerocarya birrea* fruits by gender in the study villages

3.4.5.4. Selection criteria for high quality *Sclerocarya birrea* trees

Selection of plus *Sclerocarya* trees by farmers using local criteria is shown in Table 3.10. The figures in percentage are from questionnaire analysis while the ranks are from PRA work. The most important criteria which farmers use to select *Sclerocarya birrea* was crown size, ranking first for each subspecies. The second useful criterion was trunk size; a bigger truck produces big traditional chairs and mortars. The third was fruit size, meaning that the bigger the fruit the most preferred for eating and livestock fodder. For subspecies *multifoliolata*, farmers use colour to indicate the taste of the fruits. Yellow fruits when ripe are considered the sweetest while yellowish-green are considered sour. Considerable proportion of farmers; 26.3% (Holili), 10.2% (Kiegea) and 73.8% (Malinzanga) knows and use crown size and shape as criteria for selecting good marula trees, the rest do not know any criteria. Those who knows the criteria understand that a bigger crown produce more fruits and good shade.

Table 3.10: Criteria for plus tree selection for the *Sclerocarya birrea* subspecies in Tanzania

Criteria	%age of farmers who know the criteria and rank of criteria as per PRA		
	Subsp. *birrea*	Subsp. *caffra*	Subsp. *multifoliolata*
Fruit taste	none	8.6 % : 5th	6.3 % : 4th
Fruit size	8 %:3rd	2 % : 3rd	12 % : 5th
Fruit colour	none	none	6.3 % : 3rd
Trunk size	8 % : 2nd	8.6 % : 2nd	7.2 % : 2nd
Crown size	26.3 % : 1st	10.2 % : 1st	73.8 % : 1st
Fruit production	none	0 % : 4th	none

3.4.5.5. Ownership of *Sclerocarya* trees

Not all farmers have marula trees on their farms (Figure 3.16). In Malinzanga only 8.7% of farmers have the tree on their farms; while in Holili 78.9% and in Kiegea 94.3% of the farmers have the tree on their farms. Those who didn't have the trees on their farms claimed that the trees were plenty in the wild and if they were in need of its services or goods it should not be a problem. The lack of user-right for trees growing on farms and wildlife conflicts were also put forward as barriers to retention or growing *Sclerocarya birrea* on farmlands.

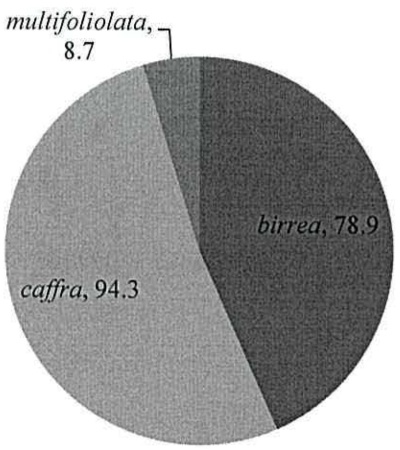


Figure 3.16: Percentage of farmers who owns marula trees on their farms

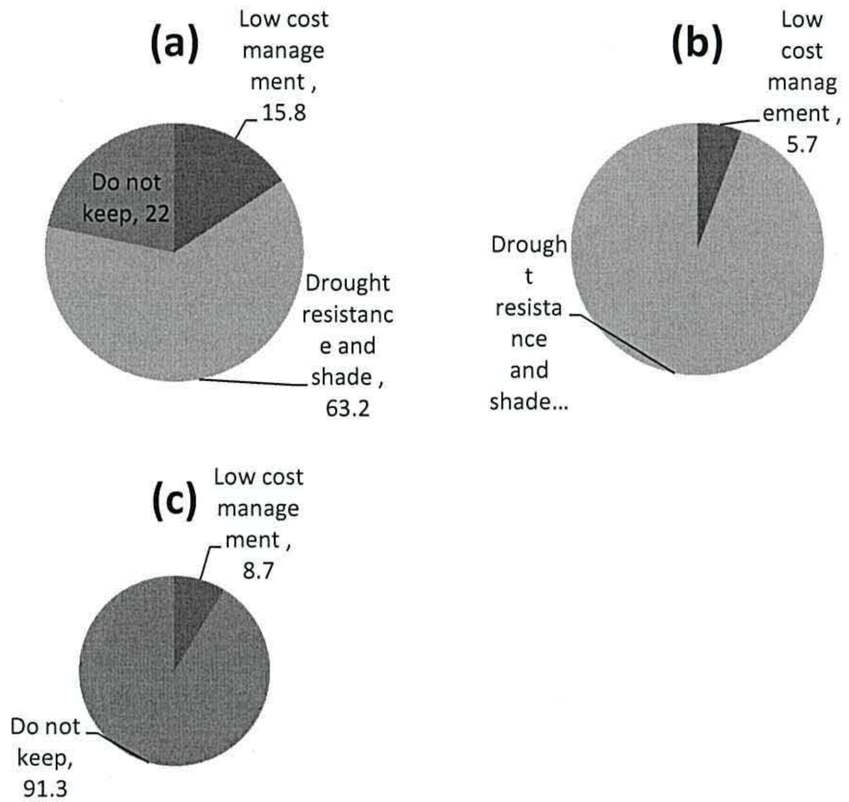


Figure 3.17: The purpose of retaining marula trees on farmers' land in Holili (a); Kiegea (b) & Malinzanga (c)

There are various factors which makes farmers retain *Sclerocarya birrea* on their farms as put forward by respondents (Figure 3.17). They include low management cost – 15.8% (Holili), 5.7% (Kiegea) & 8.7% (Mlinzanga); and the ability of the tree to perform well in prolonged dry weather while providing shade at home, on farms and in the wild – 63.2% (Holili) & 94.3% (Kiegea). These factors may be taken as among potential opportunities for promotion of domestication and commercialization of *Sclerocarya birrea.*

3.5. Discussion

3.5.1. Existing land use options and the opportunity for domestication of *Sclerocarya birrea*

Land tenure and security issues are important keys to investment and development decisions for agricultural growth for poverty and hunger alleviation in rural Africa (Sjaastad and Bromley, 1997; Place, 2009). In Tanzania the land belongs to the president as a trustee and is given to people through lease. Land in the rural area is owned under customary laws and village land act (Kusiluka *et al.*, 2011). It means if land is required for public purposes then the president through relevant departments acquire the land in most cases by compensating the owners.

There were four main ways in which land was traditionally acquired in the study villages. These were through inheritance, hiring, purchase and forest clearance or encroachment. By inheriting land it means people acquire land from parents (Magigi and Drescher, 2010) like the Kihamba system in Holili; hiring means people pay land owners in cash or part of the harvest for using land while purchase means buying land. Forest clearance or encroaching means people take advantage of open access or some form of local or customary authority over land to freely clear virgin land for agricultural purposes. They may or may not require permit from local leaders to access such resources.

Farmers are more likely to retain or plant trees on land which they have a security of ownership (German *et al.*, 2009). This makes investment in tree management on hired lands less likely because trees take long time to be harvested while there is no guarantee for tenants to retain the land for such long periods. On the other hand forest encroachment is destructive because it leads to alteration of habitats, removal of forests and eventually biodiversity loss (Norris *et al.*, 2010). Depending on interests and knowledge of farmers some species may be retained. The impacts of local knowledge on outcomes of forest encroachment was evidently different between Kiegea and Malinzanga where in both villages the system was practiced by 29.3% and 42.3% respectively. However the resulting farmlands were different because in Kiegea farmers retained most of the trees, especially *Sclerocarya birrea* compared to Malinzanga (Chapter 4).

In terms of farming systems farmers in all villages at least performs some forms of agroforestry farming, with the exception of Malinzanga were 49% of farmers practice monoculture in rice farming. Selection of trees to retain in agroforestry system, also now best referred to as agroforestry parklands (Teklehaimanot, 2008), depends on local knowledge on uses of various trees and their products. In all the villages *Sclerocarya birrea* was among the retained naturally established agroforestry tree species. Subspecies *caffra* was the most abundant tree on agroforestry parklands compared to *birrea* and *multifoliolata*. Therefore in Kiegea there were many *Sclerocarya* trees growing together with food crops on the same piece of land, probably due to its influence on crop productivity of because it was mentioned as an important shade tree. Assessing the optimum abundance of trees on farms that results into maximum crop yield seems an interesting idea. Farmers where subspecies *caffra* is found did not use industrial fertilisers, hence prompting some question on whether the species play key roles in soil fertility improvement.

The food crop component of the agroforestry systems was dominated by maize but beans, sorghum, cassava, sunflower and groundnuts were cultivated. Rice was cultivated as a monoculture crop and possibilities of incorporating *Sclerocarya* are a doubt because the farms were irrigated and fertilisers were used. Akinnifesi *et al.* (2008) reported poor performance of Uapaka kirkiana seedlings and zero effects on *Sclerocarya birrea* subsp. *caffra* when water and fertilisers were added to soil. Mateke (2000) reported that unfertilised *Sclerocarya birrea* subsp. *Caffra* survived better (100%) than fertilised ones (75%). Both authors suggest the wild and harsh environments where the trees occur naturally to be the reason for their lack of requirement of soil fertility and moisture improvements and that possibly they have evolved to perform well under harsh conditions. If the species is to be incorporated into farming systems, and especially those which require wholesome treatment such as rice farming, performance may be poor unless some specific interventions are made.

The most important uses which were identified in this study were shade, fruit as food, nuts as snacks, fodder, medicine, timber and firewood. Information on uses of *Sclerocarya birrea* subsp. *Caffra*, most of which is up to more than 50 years old, report uses on additional products such as carvings, making of ox wagons, nuts for fuel wood, and many others (Hall *et al.,* 2002). Variation in traditional knowledge is multifaceted (Steele and Shackleton, 2010) but also it may be caused by the impacts of global changes on people's ways of life. Western technologies are spreading faster while at the same time the traditional knowledge is disappearing due to negligence from modern generations, poor promotion for commercial use of the knowledge and lack documentation so that it can pass through generations. The traditional knowledge on use of *Sclerocarya birrea* may be disappearing although the lack of previous records on uses in Tanzania can only allow us to assume this. The use of *Sclerocarya* for timber for one of the subspecies prompt a necessity for planting campaigns to avoid pushing the population to unsustainable low densities. This is also important because the subspecies used for timber is *multifoliolata* whose geographic range is quite small, available only in some few localities in Tanzania (Hall *et al.*, 2002; Mouk *et al.*, 2007).

3.5.3. Potential local knowledge for improved management and use of *Sclerocarya birrea*

While subspecies *birrea* and *caffra* were regarded by farmers as unsuitable for timber and firewood due to unsuitable wood properties; subspecies *multifoliolata* was regarded as suitable for timber and firewood. The most important product of *Sclerocarya birrea* in many areas bas been the fruit (Hall *et al.*, 2002; Akinifesi *et al.*, 2008a) and reports of using it as timber are unavailable. Subspecies *Multifoliolata* scored 4/10 as a timber tree and 3/10 as a fuelwood tree indicating that it is regarded as among the useful species for its wood. It may be important to compare the strength and calorific properties of the three subspecies in Tanzania to understand if subspecies *multifoliolata* possess more suitable qualities for timber uses compared to subspecies *caffra* and *birrea*. The wood properties of *Sclerocarya birrea* subsp. *multifoliolata* have never been studied but information on subspecies *caffra* and *birrea* is available (Hall *et al.*, 2002). The objective should not necessarily be to turn the species into a timber tree but rather to understand why local people are using it for lumbering business. The knowledge will be important to identify and suggest alternative species or best practices for continued use of the species for timber. Use of the tree for wood products has already shown impacts on its abundance (DFID, 2003) while also results from Chapter 4 shows subspecies *multifoliolata*, which is the one used for timber, has the least population density especially on farms. Whether lumbering activities (in addition to wildlife conflict and lack of tree ownership) associated with the subspecies are among the contributors of its low population abundance, is beyond the scope of the current study.

All the subspecies were mentioned among the 10 most useful trees in each site, subspecies *multifoliolata* becoming 2nd, *caffra* 9th and *birrea* 6th. As a fruit tree, *T. indica*, *A. digitata* and *M. indica* ranked higher than *Sclerocarya*. But subspecies *birrea* ranked above *Mangifera indica*, *Tamarindus indica* and *Adanansonia digitata* as overall useful local trees. Although the other three trees scored ten out of ten under the category of fruits and *Sclerocarya birrea* scoring five and seven out of ten from different sites, it emerged above them due to its multipurpose value. It therefore maintained to be the most important species in Tanzania as was identified in the past by Teklehaimanot (2005). The multipurpose nature of the tree makes it suitable as the best tree for shade and among trees used for medicine, carving, firewood and timber. Unlike the fruits from the other trees, *Sclerocarya* fruits produce nuts which are used locally as snacks or in making household cooking oil. *Sclerocarya birrea* has been mentioned by farmers to be important for shade, medicine and carving in other countries (Shackleton *et al.,* 2008; de Wet *et al.,* 2010).

The fruit of the tree has been eaten by most of the people during their childhood mostly during walking livestock for grazing and going to school. Adults still perceive *Sclerocarya* fruits as important because it scored up to 7 out of 10 points as an important fruit tree, although they would not easily admit to consume it. The extent of eating *Sclerocarya birrea* fruit may be even higher because farmers have a tendency to perceive wild fruits as food for the poorest and children (Rufo, 2002) and therefore even if they consume them it is by secret. Given appropriate domestication methods are available to farmer and enough awareness campaigns are made, the tree stands good chances of successful domestication to become part of important crops to farmers.

Farmers in Kiegea perceives shade as the most important use of *Sclerocarya birrea* subsp. *caffra*, and probably that is why its on-farm population is relatively very high compared to others (Chapter 4). Although these farmers do not use inorganic fertilizers compared to those in Holili and Malinzanga villages, crop yield was fairly similar. It is therefore necessary to investigate the compatibility and effect of *Sclerocarya birrea* on performance and yield of food crops in agroforestry systems. Some agroforestry trees improve crop yields but complementarities are important because different species and patterns respond differently (Boffa, 1999; Sidibe, 2010). If found to have positive effects on associated crops; its domestication initiatives will be easily welcomed by farmers.

3.5.4. Local criteria for selection of *Sclerocarya birrea*

For all the three subspecies crown and trunk diameter were the most important criteria for selection of superior *Sclerocarya* trees. However more could be done to establish whether the preference for bigger sized trees was due to selection pressure or age of trees. All in all, farmers relate these attributes to provision of good shade as well as production of more fruits. Therefore farmers' criteria are influenced by the types of products and services they intend to get from particular trees. Other criteria used for *Sclerocarya birrea* are fruit size, quantity, color and taste. Indigenous knowledge on superior qualities of plants has been found to be as valid as knowledge produced through laboratory or western scientific approach (Thorne *et al.,* 1999). For breeding and domestication of *Sclerocarya birrea* these local criteria for plus tree selection will simplify identification of superior traits and therefore reduce the task and cost of starting from scratch.

3.5.5. Institutional potentials and barriers associated with use and management of *Sclerocarya birrea*

Local people have interacted with their environments and over time developed useful knowledge in bioprospecting and plant domestication in general (Dovie *et al.,* 2008). A significant contribution to global knowledge has originated from local indigenous people and is a key pillar of economic development of particular countries or societies (Brooks and and McLachlan, 2008). Local peoples' knowledge therefore is a good pointer of the direction to take towards improved management and utilisation of resources. After all it is based on years of experimentation and experience, only lacking documentation and formalisation like the conventional scientific knowledge. The use of such knowledge over time has created institutions for management of resources, which are referred to as rules of the game (Larson, 2010) and are central to traditional management and utilisation.

Despite having local knowledge on use and management few farmers have *Sclerocarya* on their farms in Holili and Malinzanga. Reasons for these are poor understanding of legal institutions, wildlife conflicts, ignorance of the tree values and plentiful of the trees in the wild. Many farmers think that all trees belong to the government and for one to harvest will require applying for a user-right permit. Although this may largely be a misconception of the forest act, it significantly affects tree planting and management in agroforestry systems. For protection of endangered species, the forest act requires application of a permit for any use intended for some listed tree species (MNRT Forest Act., 2002). As a result of insufficient public education many farmers thinks every tree species require permits or at least they do not know the species in the protected trees list. Therefore the totality of this bureaucracy influences the willingness of farmers to domesticate trees on their private lands. Relevant authorities and stakeholder may need to devise mechanisms for ensuring the species protection act is clarified to the community. Unless this is done, reluctance on tree planting and management will continue in the wider community, eventually the act may lead to reduced number of trees in the environment instead of promoting conservation and biodiversity improvement.

Sclerocarya trees were also perceived as cover and corridor for wildlife which is destructive to crops such as monkeys and birds. Because of this, some farmers would intentionally remove seedlings and cut down branches to avoid the animals. These wildlife conflict problems are a real challenge since solutions are not easy to find (Sillero_Zubiri and Switzer, 2001). Guarding, trapping, noise making, chasing, poisoning, use of scents, fencing, scarecrows, plastic flags and fireworks have been used traditionally for crop protection against wildlife but success is minimal and the techniques may be expensive and time/energy consuming. Alternative means for crop protection needs to be devised and given to farmers to improve impacts of domestication campaigns.

Farmers know uses of *Sclerocarya birrea* although seldomly uses the fruits. The reason for this may be because exotic fruits such as mango have been promoted for years (Jama *et al.,* 2008). But lack of awareness of types of products which can be developed from the fruits and the market they hold is also a barrier. Farmers do not sale any product from *Sclerocarya birrea* in the study villages. The barrier to commercialization of the species was mentioned to be lack of knowledge on products, markets and entrepreneurship. *Sclerocarya birrea* fruits are traditionally used to make juice, jam and wine/beer in other countries and has shown to be profitable (DFID, 2003) and is reported to be liked by many people in west Africa (Sidibe, *pers. comm.*). It is therefore important to preserve and share local knowledge on using of *Sclerocarya birrea* fruits, which has proved to be variable between communities where the tree occurs (Hall *et al.,* 2002; Ngiitolwa *et al.,* 2003; DFID, 2003).

Since the farmers in Tanzania together with the government are looking for means of income diversification and improvement, improved awareness and eventual domestication and trade on *Sclerocarya birrea* is a lucrative option.

Other barriers include lack of knowledge on propagation and silviculture of *Sclerocarya birrea*. For domestication to be successful farmers needs to be given the most appropriate method for propagating the tree as well as on how to manage it. Lack of improved germplasm (Jama *et al.,* 2008) and cost-effective propagation techniques (Amri, 2009) are among the important barriers to domestication of indigenous trees in Africa. Farmers have knowledge on selection of superior genotype and understand the phenology of the tree, using participatory approaches their knowledge on domestication and management can be significantly improved.

3.5.6 Local infrastructure important for development of *Sclerocarya birrea*

There was no trade of *Sclerocarya* fruits in the study areas largely due to institutional barriers which include ack of markets, abundance of the fruits in the wild and competition from more developed exotic fruits. In presence of *Sclerocarya* trade, farmers would sell its fruits or products along with harvests from other crops in order to generate cash for meeting goods and services they don't produce at home. The availability of markets, good prices and transportation are vital. In this study most farmers were selling crops (excluding *Sclerocarya*) from their homes to middlemen who would in turn transport the crops to towns and cities for sale. Other farmers take their crops to the markets themselves. Presence of FM radios and extensive mobile telephone network aids farmers to exchange and update prices across the country, hence avoiding underpayment from middlemen. It has been reported that the expansion of mobile phone coverage is drastically changing and helping farmers in rural Africa in the way they choose markets and set prices (Muto and Yamano, 2009). By using cell phones, farmers call their colleagues to seek and share current prices for different crops in different areas and therefore avoiding selling crops at falsely low prices. The presence of such communication medium is a potential advantage towards interventions for successful improved management and trading of *Sclerocarya birrea* in Tanzania.

The mostly used means of transport of crops or farmers travelling from one place to another is foot and bicycle. Roads are in relatively satisfactory condition except in

Holili where during rain seasons roads are almost impassable. Roads are important in facilitating transportation of crops and distribution of agricultural inputs. Poor roads and therefore market access, for instance, increases input costs, and transport costs effectively reducing the net profits from farm products and also discourages farmers who participate in production of perishable crop products (Yamano and Kijima, 2010) such as *Sclerocarya birrea* fruits. For improved production and trade of *Sclerocarya birrea* products in future the conditions of the roads need to be maintained and improved in areas like Holili. Good roads, public transport and truck service will improve and perhaps save farmers from the laborious task of using foot and bicycle means of travel and transportation of *Sclerocarya birrea* fruits and other crops.

Results from this chapter have established that there is a variation in traditional knowledge associated with the use of the three subspecies. The variations involve aspects of preferences and types of goods and services from the species and management style within the existing agroforestry systems. These variations need to be noted carefully as they may either relate to the differences in the subspecies (e.g. the use of S. multifoliolata for timber) or to the knowledge held by the different villagers or both. Future surveys may improvise by for instance including more study sites per subspecies and assessing the physical and chemical properties of the tree e.g. its wood.

Similarities were noted with respect to barriers to utilisation and criteria for plus tree selection. Lack of trade on raw or processed products due to unestablshed local market was a major setback in efforts to tap the potentials of the species. Awareness created through this research resulted into few farmers developing interest and designing beverages from the fruits which have started to be consumed locally. This is a promising signal towards improved management and utilisation of the species. Also farmers have a perceived lack of ownership and authority over trees due to misunderstanding of the protected species law. This is a problem which discourages them from planting or retaining trees on their farms and needs to be addressed by relevant authorities.

CHAPTER FOUR: POPULATION STATUS AND ASSOCIATED TREE SPECIES OF *SCLEROCARYA BIRREA* IN TANZANIA

4.1 Introduction

4.1.1 Background

Tanzania is regarded as the centre of diversity for Marula (Gillet and Kokwaro, 1980; Kadu *et al.*, 2007; Teklehaimanot, 2008) but its populations are the least studied. Much of the available knowledge on Marula is based on subsp. *caffra*. Analysis of the available information on biology and use conclude that much is known about the fruit and its uses –including policy, marketing and processing propositions, but information on the species' natural populations is fragmentary. In the past decade several studies on domestication, growth, fruit production, phenology, use, post-processing waste handling and traditional knowledge have been done in eastern and southern Africa excluding Tanzania (Khonje *et al.*, 1999; Shackleton *et al.*, 2002, 2006; Akinnifesi, 2004, 2006, 2008; Leakey *et al.*, 2005; Karin & Nontokozo, 2006; Mghomba, 2008; Teklehaimanot, 2008; Strong, 2009). Although it provides crucial information and tool for sustainable management, population status for *Sclerocarya birrea* remain less studied in most of the countries (Hall *et al.*, 2002; DFID, 2003, Witowsky *et al.*, 2008).

Existing information on stand density of *Sclerocarya birrea* is largely based on information from records of occurrence or wholesome vegetation assessments (Hall *et al.*, 2003; Shackleton *et al.*, 2003) although very few from formal inventory of subspecies *caffra* in South Africa and Namibia and subspecies *birrea* in Benin (DFID, 2003; Ngiitolwa *et al.*, 2003; Gouwakinnou *et al.*, 2009) have been done. Despite the highest genetic diversity of *Sclerocarya birrea* and availability of all its three subspecies in Tanzania, the country's populations have never been inventoried before. Given its importance and the call for its incorporation into tree improved management and development programs, population studies in many areas where the species occur are needed to provide a useful tool for management and utilisation. It is especially important to study the subspecies in Tanzania, not only because this has never been done before but also because the tree ranks high in its potential to become a major domesticated crop in future.

For a long time useful trees have been considered plenty in the wild, with complex regeneration biology, slow growing and inappropriate for cultivation by farmers. This perception has been aggravated by limited knowledge on economic value, ecological variations and population structure of specific species in the Miombo. Following the same trend, for many years in Tanzania research on silviculture, tree growth and stand structure mainly focused on plantation forests aimed for timber and some other wood products production, exacerbating the ignorance on indigineous tree species. The growing number of commercialisation initiatives based on scanty fruit production data on *Sclerocarya birrea* should be cause for concern. The encouragement of small or large-scale enterprises is dependent upon the existence of adequate and sustainable resources to supply the commercialisation drives. If there are inadequate resources, then the stability of *S. birrea* populations and the commercial enterprises will be jeopardised to the detriment of both, and ultimately the rural populations that have used the resource for millennia. The range of required knowledge is broad but in the end densities of adult trees, regeneration status, size-structure profiles and tree growth rates for wild populations are also as important (Shackleton, 2002).

Little is known about the regeneration ecology of this species in its natural habitat (Helm and Witowski, 2008; Akinnifessi *et al.*, 2008; Gouwakinnou *et al.*, 2009) while its influence on soils and species composition around its habitat is old and scant (Hall *et al.*, 2002). Studies are needed to understand the recruitment nature of the species which grows in areas with frequent disturbances (Helm and Witkowski, 2008). In the 1990s, large numbers of unimproved seedlings of *Sclerocarya birrea* were distributed to farmers as one of the efforts to establish the tree on farms as an agroforestry species in southern Africa. This early enthusiasm was short-lived as graft-take became as low as 10% (Jaenicke *et al.*, 2001) and low survival and growth were reported on farmers' fields (Mhango & Akinnifesi, 2001). For this reason, the recruitment of new individuals for the species remains natural both in the wild and on farms. Natural regeneration is an important process in perpetuation of plant communities in their natural habitats as well as sustainable utilisation (Tesfaye, 2010). Natural regeneration of tree species takes place either through seeds or vegetative means mainly through root or coppice sprouting. It is known that on tropical mainland especially in the dry forests, more than 90% of all tree species have more than 50% of their seeds killed by predators or fruit fungi between fruit set and seed germination. All these factors together with nutrient relations and herbivory; control the growth and reproduction from seeds (Harper *et al.*, 1965; Malaisse, 1978; Hutching, 1986; Janzen and Yanes, 1991; Chidumayo, 1993; Grundy *et al.,* 1993; Chidumayo and Frost, 1996; Chidumayo, 1997).

However, the main form of natural vegetation regeneration is not through seeds but through root suckering and coppicing. These usually occur following disturbances imposed on the natural communities such as logging and land clearing (Mugasha, 1978). After establishment seedlings and saplings pass through a difficult transition to establish into the tree layer due browsing and fire (Higgins *et al.*, 2000; Bond & Midgley 2001; House *et al.*, 2003; Hanan *et al.*, 2008). Seedlings suffers top kill from fire and they need to take time to establish structures such as lignotubers to be able to re-sprout to their previous size (Hofmann, 1998; Hofmann and Solbrig, 2003). Saplings also need a minimal disturbance for them to recruit into the canopy layer where there is less damage (Lehman *et al.*, 2009). Hence disturbances affects and shape population structure and status of a species since it determines the amount of trees attaining the mature reproductive stage (Higgins *et al.*, 2000; Hanan *et al.*, 2008).

While regeneration determines adult population structure for a species, soil properties and species associates are also important habitat components with influences on performance of species. *Sclerocarya birrea* is found in mixed deciduous woodland and wooded grassland; in most case reported to be associated with Lannea and Combretum spp. (Mbuya *et al.*, 1994; van Wyk & van Wyk, 1997; Salim *et al.*, 2002; Rufo, 2002; AFREA, unpublished). The different subspecies are reported to be associated with different vegetation and species types (Hall *et al.*, 2002). The available information is based on generalised vegetation reviews and it is suggested that localised variations are possible. For the case of Tanzania where all the subspecies occurs, we do not know if there is an overlap of the associates.

On the other hand information on soils found where the species occur is restricted to general texture (Hall *et al.*, 2002). Sandy texture is the most commont although sandy loam and loam are also mentioned. There is scant information about pH (commonly from 4.8 to 6.2 and occasionally alkaline) (Morrison *et al.*, 1948; Vollesen, 1980) and soil fertility is said to be generally poor (Ohler, 1985) with a few exceptions (Trapnell, 1953).

The regeneration mode for the three subspecies has never been compared and especially taking into account the wild and farm environment where it occurs. We also do not know whether the species, which despite its valuable ecological role in the wild (Hall *et al.*, 2002; Shackleton *et al.*, 2002; Helm *et al.*, 2008) and grows in association with crops on farms, influence the basic soil properties around its habitat. Although there is a general literature about the species' vegetation associates; it has been suggested that local variation are possible (Shackleton *et al.,* 2003). All the three subspecies occur in Tanzania and present a unique opportunity to study and compare the respective habitats. If this knowledge is acquired, it can be important in sustainable use and conservation initiatives for the species (Helm and Witowski, 2008).

Given this background we studied and compared the basic population status, soil properties, regeneration mode and record species associated with the three subspecies of *Sclerocarya birrea.*

4.1.2 Study Objectives and hypothesis

Specific objectives

i. To analyse the basic properties of soils in areas where *Sclerocarya birrea* grows

ii. To assess and compare the population density, size and sex distribution pattern of the three subspecies of *Sclerocarya birrea* populations in Tanzania

iii. To assess and compare the types of natural regeneration and the corresponding density and sizes of regenerants for the three subspecies of *Sclerocarya birrea* in Tanzania

iv. To inventory and compare tree species which share habitat with each of the three subspecies of *Sclerocarya birrea* in Tanzania

Hypothesis

The following hypothesis were used to guide this scientific investigation

- Size and sex distribution of *Sclerocarya birrea* is not similar within and between the three subspecies both on farm and in the wild conditions
- There are more female than male trees in each of the subspecies
- The density of *Sclerocarya birrea* trees in the wild is less than that of on-farms environment; and it does not differ between the three subspecies,

- The frequency of vegetative and sexual regeneration is not the same for the three subspecies of *Sclerocarya birrea* regardless of wild or on farm environment
- The composition of tree vegetation in areas where *S. birrea* is found is not similar among the three subspecies both on farm and in the wild

4.2 Materials and methods

4.2.1 Study sites

The study was carried out in three villages namely Holili, Kiegea and Malinzanga in which the subspecies *birrea, caffra and multifoliolata* respectively were studied. In each village two site conditions (natural woodland and cultivated farm land) were sampled and at each site condition one sampling plot was established for population survey.

4.2.2 Sampling procedure

In each village *Sclerocarya birrea* were sampled in two environmental settings, i.e. the wild and on-farm. At each site condition one sampling plot was established for population survey. Thus a total of six populations were studied. In establishing a study sample, a plot-less sampling and nearest neighbor tree technique as described by Cottam and Curtis (1956) and Williams *et al.* (1969) was adapted. This method, with some modification, is believed to suit various field conditions and specific objectives (Ludwig & Reynolds, 1988; Hutcheson *et al.*, 1999; Sparks *et al.*, 2002; Sheil *et al.*, 2003; van der Maarel, 2005). It is also superior in saving time, energy and money while attaining higher levels of accuracy especially for trees with Diameter at Breast Height (DBH) ≥ 10 cm and which are sparsely distributed. Even in populations which are unevenly scattered, plotless sampling remains valuable and biases are insignificant (Lessard *et al.*, 1994).

To get a study sample in each population, a mature *Sclerocarya* tree (≥ 10 cm dbh) was first located roughly at centre of the population. From this tree, a progressive outward movement was made by adding more individuals but keeping the sample compact until 100 mature individuals were included. This means that the sizes of the plots varied depending on the *Sclerocarya* stocking density i.e. variable plot size sampling.

4.2.3 Data collection

For each tree included, DBH, height to the crown summit and height to the first branch were measured. Crown diameter was derived by measuring two diameters perpendicular to each other at 90° through the crown vertical projection. The mean of the two crown measurements was then used as crown diameter value for each tree.

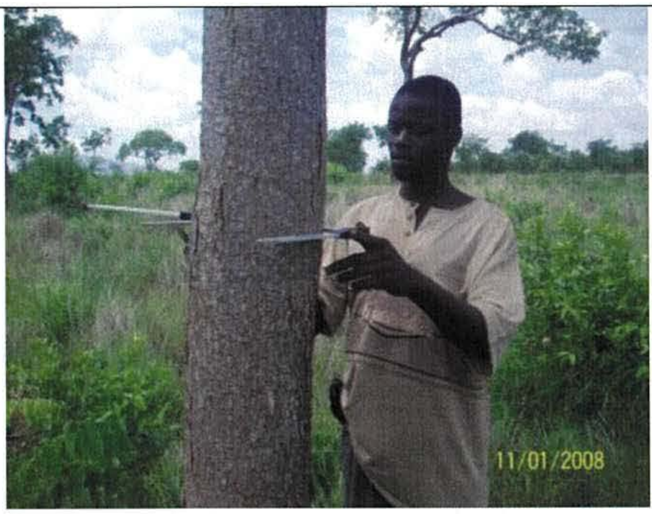


Plate 4. 1: Measuring diameter (DBH) of *Sclerocarya birrea* subsp. *caffra* in Kiegea, Tanzania

Further to the above measurements, coordinates (easting (x) and northing (y) for all 100 *Sclerocarya* trees at a site were recorded using a differential GPS in Universal Transverse Mercator (UTM) system.

The soil in each environmental condition (on farm and wild areas) was characterized to get an overall status of soil basic properties. Soils were collected under and away from five randomly selected *Sclerocarya birrea* trees per environmental condition. To do this, at each sampling location, a trench was dug to expose the soil horizon. Soil was collected at depths of 0-20 and 20 – 40 cm, excluding the top litter layer. This made a total of 40 samples per subspecies' site 10 samples under trees and 10 samples away from trees; hence 20 samples from on farm and 20 samples from wild environment. The samples were put into a black polyethene bag with labels made by cutting pieces from cardboards indicating location and depth of sample collection included inside the bags. They were transported to Sokoine University Soil Science Department Laboratory for analysis.

The area occupied by the 100 mapped trees was divided into 20 m x 20 m square grids and 10% of the grids were randomly selected for regeneration study. We therefore surveyed 26 and 3 plots in Holili on farm and wild environments; 3 plots for each of Kiegea sites and 24 and 6 plots for on farm and wild environments in Malinzanga. To assess the natural regeneration, the numbers of saplings and seedlings were enumerated in each of the selected sample grid. Seedlings (<1 m tall) and sapling (< 10 cm dbh but ≥ 1m tall) were categorized as either arising from seed or stumps (coppices) and roots (sprouts).

Associated neighboring woody species (≥ 10 cm dbh) encountered close (within 20 m radius) to each mapped *Sclerocarya* tree was identified and enumerated. Dendrometric measurements were not made for the associated species because they were not the focus of the study.

4.2.4 Data analysis

Excel program was used to process and analyze morphological attributes which were later summarized into graphs and tables. DBH was summarized into eight classes (10.0-20.0; 20.1-30.0; 30.1-40.0; 40.1-50.0; 50.1-60.0; 60.1-70; 70.1-80.0; >80.0 cm); while branching height had five classes (<1.5; 1.6-3.0; 3.1-4.5; 4.6-5.0; 5.1-7.5 m). Tree height had four classes (<5.0; 5.1-10.0; 10.1-15.0; 15.1-20.0 m) while crown diameter had seven (<2.0; 2.1-5.0; 5.1-8.0; 8.1-11.0; 11.1-14.0; 14.1-17.0; >17.0 m). Description and comparison of the subspecies was done through One-way ANOVA while independent T-test was used to test differences between the two environmental conditions and tree sexes. Correlation was done to analyze the relationship between diameter, height, crown-size and site elevation. All statistical analyses were done on Minitab and Excel.

From the coordinates established above, the nearest neighbor distance (meters) for each pair of trees was calculated using Arc View. To determine the tree distribution pattern, the Clark and Evans (1954) technique was used. The technique assumes that, in a population with N individuals with known density d and nearest neighbor distance r from pair trees, the mean observed distance is represented as $ro = \sum r/N$. The mean distance which would be expected if the population was randomly distributed, re; has a value equal to $re = 1/2\sqrt{d}$ (i.e. the reciprocal of $2\sqrt{d}$). The degree to which the observed distribution approaches or departs from random expectation with respect to the distance to nearest neighbor is expressed as a ratio $R = ro/re$. According to Clark and Evans (1954), R has a limited range: $0<R<2.1491$. When $R = 0$, there is a situation of complete aggregation; when $R = 2.1491$ there is completely uniform distribution pattern and when $R = 1$ the distribution pattern of individuals is said to be random.

The data on regeneration was used to generate absent-present species list, number of associated species stems per hectare and diversity indices of the associated species. Diversity indices calculated were Species Richness and Simpsons' Index. Species Richness is a measure of the number of different kinds of species present in a particular area. However, diversity depends not only on richness, but also on evenness. Evenness compares the similarity of the population size of each of the species present. A community dominated by one or two species is considered to be less diverse than one in which several different species have a similar abundance. As species richness and evenness increase, so diversity increases. Simpson's Diversity Index is a measure of diversity which takes into account both richness and evenness. Simpson's Index (D) measures the probability that two individuals randomly selected from a sample will belong to the same species. The value of D ranges between 0 and 1, 0 represents infinite diversity and 1, no diversity. That is, the bigger the value of D, the lower the diversity. This is neither intuitive nor logical, so to get over this problem, D is sometimes subtracted from 1 to give Simpson's Index of Diversity 1 – D (Simpson, 1949; Lamb *et al.,* 2009).

Soil properties analysed, following the methods used by Mwang'ngo *et al.* (2002), included pH which was measured potentiometrically (1:2.5 solid to liquid ratio, organic carbon through wet oxidation-redox titration method, total nitrogen by measuring the amount of ammonium evolved, available phosphorus determined calorimetrically through Olsen method using ammonium molybdate as a colouring reagent and exchangeable bases (Calcium, Magnesium, Potassium and Sodium) through $BaCl_2$ method. Soil texture analysis was also done to classify the soils into various percentages proportions of sand, silt and clay. The classes obtained were Sandy Clay Loam (SCL), Sandy Loam (SL) and Loamy Sand (LS).

4.3 Results

4.3.1 Basic properties of soils associated with *Sclerocarya birrea* populations

There were in total six populations studied: three on farm and three in the wild (three sites). There were differences in soil characteristics between the sites where each subspecies of *Sclerocarya* occur but also between wild (W) and on farm (F) sites as well as between soils collected under and away from the trees. The differences between soils under and away from trees indicate that *Sclerocarya birrea* influences soil properties especially organic matter composition and soil pH. However confounding factors such as presence or absence of other associated species and human practices may influence the findings. Results for various soil parameters analyzed in the laboratory are shown in Table 4.1a & b. For subspecies *caffra* habitat in Kiegea, which is in central part of the country, soils under the trees were slightly acidic (pH 6.75 ± 0.10); whereas the habitat for subspecies *birrea* in Holili, in the north and subspecies *multifoliolata* habitat in Malinzanga, in the south of the country were slightly alkaline with pH 8.40 ± 0.32 and pH 7.64 ± 0.1 respectively (Table 1.1a). Away from the trees the soils in Holili remained slightly alkaline while in Kiegea and Malinzanga the soils were slightly acidic (Table 1.1b). The habitats for subspecies *birrea* and *multifoliolata* are both on a higher altitude, at 879 ± 3 and 954 ± 1 *m.a.s.l.* respectively; than the habitat for subspecies *caffra*, 520 ± 1 *m.a.s.l.*

Figures for mean and standard error for organic matter (%), total nitrogen (%N), exchangeable bases (N, P, K, Na) and soil texture are many but can be followed in Table 4.1 a & b. They show that soils in the wild population had more percentage of organic carbon than those on farm, with a slight exception of soils in Malinzanga indicating that the difference in organic carbon composition was likely due to land use type rather than type of subspecies/site studied. Distinctive pattern was missing in terms of percentage total nitrogen and amount of exchangeable bases with the exception of potassium (K^+) which was observed to be higher in the area where subspecies *caffra* occurs. All soils had a higher percentage of sand with the population of subspecies *caffra* being found on soils with the highest proportion of sand, 80% for wild environment and 83% sand for on farm environment (Table 4.1a-b). In terms of USDA classification soils in Holili (subspecies *birrea*) and Malinzanga (subspecies *multifoliolata*); on farm and wild soils resembled each other i.e. sandy clay loam (scl) for on farms soils and sandy loamy (sl) for wild soils. The soils in Kiegea (subspecies *caffra*) were loamy sand (ls).

Table 4. 1a: Soil properties for the three populations in both wild (W) and on farm (F) conditions for samples collected ***under*** the trees

Item	Soil depth(cm)	Study subspecies / site						Remarks
		S. birrea		*S. caffra*		*S. multifoliolata*		
		Holili F	Holili W	Kiegea F	Kiegea W	Malinzanga F	Malinzanga W	
Soil pH (1:2:5-H_2O)	0-20	8.40 ± 0.32	7.34 ± 0.09	6.75 ± 0.10	7.44 ± 0.12	7.64 ± 0.16	7.20 ± 0.12	S*, D*
	20-30	7.37 ± 0.11	7.03 ± 0.16	6.73 ± 0.04	6.35 ± 0.27	7.16 ± 0.24	7.06 ± 0.05	
Organic carbon (%)	0-20	1.09 ± 0.13	1.40 ± 0.15	1.16 ± 0.02	1.22 ± 0.09	1.82 ± 0.16	0.70 ± 0.03	D**
	20-30	0.67 ± 0.18	0.97 ± 0.24	1.14 ± 0.01	0.93 ± 0.06	0.54 ± 0.07	0.93 ± 0.11	
Total Nitrogen (%)	0-20	0.11 ± 0.01	0.08 ± 0.02	0.12 ±0.01	0.15 ±0.01	0.18 ± 0.01	0.12 ± 0.02	S*
	20-30	0.13 ± 0.01	0.14 ± 0.01	0.12 ± 0.01	0.14 ± 0.01	0.06 ± 0.03	0.08 ± 0.01	
ca^{2+} ($cmol^{+}/kg$)	0-20	3.80 ± 1.21	1.12 ±1.36	3.34 ± 0.61	4.34 ± 0.15	7.50 ± .0. 27	0.94 ± 0.02	
	20-30	2.73 ± 1.02	3.60 ± 0.92	3.21 ± 0.33	4.05 ± 0.22	1.17 ± 0.62	2.62 ± 0.84	
Mg^{2+} ($cmol^{+}/kg$)	0-20	1.47 ± 0.71	1.28 ± 0.54	2.39 ± 0.28	2.36 ± 0.15	2.93 ± 0.33	2.39 ± 0.71	S*, E*
	20-30	3.69 ± 1.12	1.29 ± 0.19	1.95 ± 0.16	2.48 ± 0.47	2.55 ± 0.51	1.79 ± 0.28	
K^{1+} ($cmol^{+}/kg$)	0-20	0.13 ± 0.03	0.30 ± 0.01	0.25 ± 0.01	0.72 ± 0.03	0.09 ± 0.01	0.32 ±0.01	S**, E**
	20-30	0.07 ± 0.01	0.23 ± 0.01	0.50 ± 0.22	0.67 ± 0.01	0.13 ± 0.02	0.25 ± 0.03	
Na^{1+} ($cmol^{+}/kg$)	0-20	0.32 ± 0.04	0.31 ± 0.01	0.32 ± 0.04	0.39 ± 0.03	0.31 ± 0.02	0.36 ± 0.01	
	20-30	0.84 ± 0.08	0.27 ± 0.01	0.29 ± 0.05	0.37 ± 0.01	0.27 ± 0.04	0.35 ± 0.05	
Clay (%)	0-20	23.16± 1.05	17.65 ±1.31	17.48 ± 1.06	17.01 ± 1.92	31.21 ± 1.23	29.32 ± 2.66	S**, E**, D
	20-30	27.23 ± 2.11	15.14 ± 1.26	15.29 ± 1.11	15.27± 0.81	19.06 ± 2.17	19.46 ± 1.74	
Silt (%)	0-20	7.11 ± 0.94	7.81 ± 0.76	1.03 ± 0.21	3.11 ± 0.28	9.39 ± 1.89	7.08 ± 0.94	E**
	20-30	9.47 ± 1.23	9.38 ± 0.75	1.62 ± 0.33	5.42 ± 1.07	5.72 ± 0.30	5.25 ± 2.08	
Sand (%)	0-20	70.06 ± 1.66	76 ± 0.06	84.32 ± 0.88	82.11 ± 1.29	60.63 ± 0.65	64.18 ± 1.27	E**
	20-30	64.17 ± 2.91	76 ± 0.32	82.03 ± 1.08	78.39 0.99±	76.14 ± 1.08	76.43 ± 0.82	
USDA Class		SCL	SL	LS	LS	SCL	SL	

Remarks: Significant difference found between (S = Subspecies location/Site; E = Environment; D = Depth); ** = $p < 0.001$; * = $p < 0.01$

Table 4.1b: Soil properties for the three populations in both wild (W) and on farm (F) conditions for samples collected ***away*** from the tree

Item	Soil depth(cm)	Study Subspecies / Site						Remarks
		S. birrea		S. caffra		S. multifoliolata		
		Holili F	Holili W	Kiegea F	Kiegea W	Malinzanga F	Malinzanga W	
Soil pH (1:2:5-H2O)	0-20	7.04 ± 0.61	7.42 ± 0.21	6.48 ± 0.06	6.81 ± 0.33	6.35 ± 0.48	6.11 ± 0.04	S**
	20-40	7.10 ± 0.17	7.17 ± 0.08	6.73 ± 0.04	6.27 ± 0.14	6.12 ± 0.05	6.01 ± 0.07	
Organic carbon (%)	0-20	0.66 ± 0.25	0.91 ± 0.22	1.09 ± 0.06	1.28 ± 0.11	0.61 ± 0.20	0.51 ± 0.16	S**, D*
	20-40	0.61 ± 0.08	0.59 ± 0.24	0.86 ± 0.05	0.75 ± 0.37	0.44 ± 0.12	0.51 ± 0.07	
Total Nitrogen (%)	0-20	0.15 ± 0.01	0.13 ± 0.04	0.09 ±0.02	0.11 ±0.01	0.10 ± 0.04	0.14 ± 0.01	S*, D**
	20-40	0.12 ± 0.02	0.10 ± 0.01	0.09 ± 0.01	0.09 ± 0.02	0.11 ± 0.07	0.09 ± 0.01	
ca2+ (cmol+/kg)	0-40	4.11 ± 1.68	4.36 ±0.97	3.15 ± 1.02	3.68 ± 0.44	2.74 ± 0. 61	1.89 ± 0.11	S**
	20-40	3.54 ± 0.82	2.86 ± 1.73	3.06 ± 0.61	3.39 ± 0.27	2.21 ± 0.33	1.09 ± 0.28	
Mg2+ (cmol+/kg)	0-20	2.08 ± 0.14	1.11 ± 0.10	2.39 ± 0.28	2.36 ± 0.15	2.93 ± 0.33	2.39 ± 0.71	S**
	20-40	1.96 ± 0.15	1.35 ± 0.11	2.16 ± 0.21	2.48 ± 0.47	2.55 ± 0.51	1.79 ± 0.28	
K1+ (cmol+/kg)	0-20	0.13 ± 0.03	0.28 ± 0.02	0.20 ± 0.02	0.63 ± 0.08	0.06 ± 0.01	0.19 ±0.11	S**, E**
	20-40	0.15 ± 0.01	0.31 ± 0.01	0.33 ± 0.06	0.34 ± 0.15	0.04 ± 0.01	0.08 ± 0.01	
Na1+ (cmol+/kg)	0-20	0.37 ± 0.02	0.22 ± 0.04	0.14 ± 0.01	0.45 ± 0.13	0.19 ± 0.05	0.42 ± 0.08	E*, D**
	20-40	0.12 ± 0.03	0.18 ± 0.01	0.16 ± 0.01	0.15 ± 0.06	0.12 ± 0.01	0.25 ± 0.04	
Clay (%)	0-20	26 .09± 0.85	22.14 ±1.31	16.11 ± 2.11	17.27 ± 2.02	28.06 ± 0.77	30.91 ± 0.47	S**
	20-30	27.52 ± 3.43	13.22 ± 1.08	14.45 ± 1.32	23 61± 1.47	21.31 ± 1.48	24.12 ± 2.03	
Silt (%)	0-20	6.32 ± 0.43	8.05 ± 0.31	3.14 ± 0.17	2.92 ± 0.11	12.02 ± 0.36	10.53 ± 1.76	S**, D**
	20-40	6.71 ± 0.58	6.11 ± 0.23	1.42 ± 0.41	2.35 ± 0.10	9.18 ± 1.06	4.12 ± 1.16	
Sand (%)	0-20	76.11 ± 2.07	71.93 ± 0.27	86.13 ± 0.09	86.13 ± 0.56	64.03 ± 1.19	72.39 ± 1.43	S**, D*
	20-40	70.35 ± 1.48	69 ± 0.12	83.13 ± 1.18	79.21 1.09±	73.32 ± 2.65	70.08 ± 0.67	
USDA Class		SCL	SL	LS	LS	SCL	SL	

Remarks: Significant difference found between (S = Subspecies location/Site; E = Environment; D = Depth); ** = ($p < 0.001$); * = ($p < 0.01$)

4.3.2 Stand density of the subspecies of *Sclerocarya birrea*

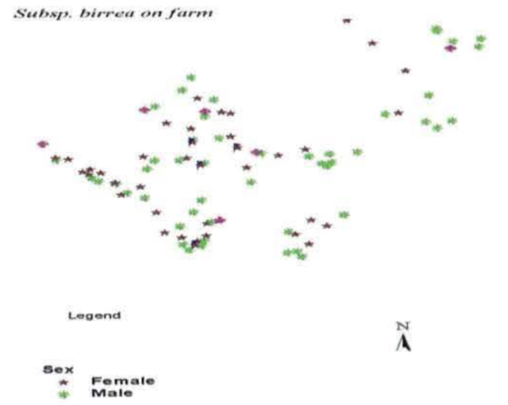
With the exception of the subspecies *caffra* population, which occurs in east-central Tanzania, wild populations were denser than the populations on farmland areas. The densest population was that of subspecies *caffra* on farms with 20.4 stems ha^{-1}. From chapter 3 results show that farmers in the site where caffra is found do not use inorganic fertilizers, raising speculation that marula might have influence on performance of intercrops. There is no proof of this since the component of impact of marula on performance of intercrops was not coverd and therefore future research may consider it. The least dense was that of subspecies *birrea* on farmland environment with 1.5 stems ha^{-1} (Table 4.2).

Table 4. 2: Stand population density in stems ha^{-1} for the different subspecies and site condition

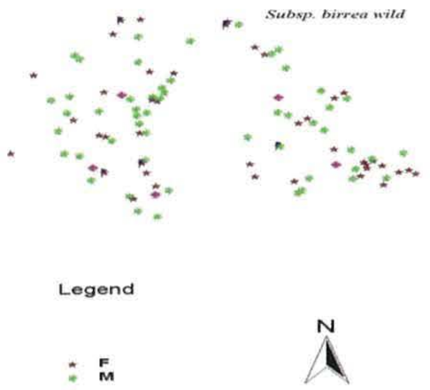
Population	Site condition	Sampled area (ha)	Stems ha^{-1}
S. birrea	on farm	66.15	1.5
	wild	5.88	17.0
S. caffra	on farm	4.91	20.4
	wild	6.83	14.6
S. multifoliolata	on farm	58.79	1.7
	wild	11.70	8.5

4.3.3 Spatial distribution of trees and sex in *Sclerocarya birrea*

Results showing the spatial distribution of female and male trees for each population is presented in plate 4.2, while Table 4.3 shows the tree density ***(d)***, observed nearest neighbor distance ***(ro)***, expected nearest neighbor distance ***(re)*** and measure of degree to which the observed distribution approaches or departs from random expectation ***(R)*** for all the sites. The observed nearest neighbor distance (r_0) for Kiegea site, (on farm and in the wild respectively), was shorter (12.80 ± 0.90 m and 13.60 ± 1.09 m) than that in Holili (32.37 ± 2.45 m and 11.71 ± 0.77 m) and Malinzanga (35.23 ± 3.26 m and 14.11 ± 1.17 m). Therefore in Kiegea where r_0 for wild and on farm populations were more or less equal (figure 4.1), the wild population of Malinzanga and Holili had r_0 which was shorter than the respective on-farm population. However for all the populations the r_0 values were close to r_e values hence resulting into R values close to 1.00, implying that the distribution pattern for all populations was almost completely random. With the exception of the Kiegea population, one way ANOVA and independent t-test showed a significant difference ($p < 0.05$) for mean nearest neighbor distance and between the on-farm and wild populations.



(Plot size = 66.15 Hectares)



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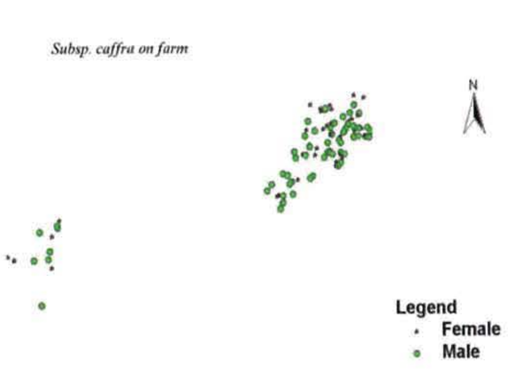
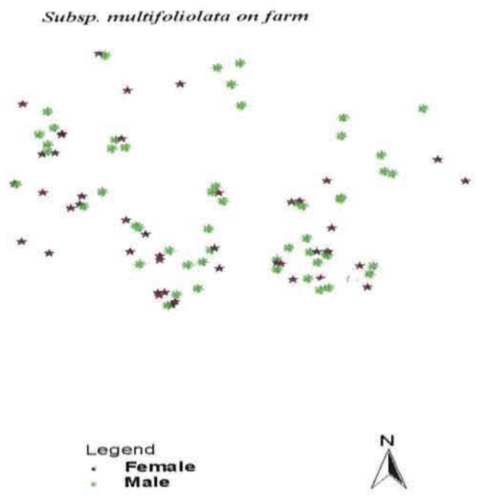


(Plot size = 4.91 Hectares)

(Plot size = 6.83 Hectares)



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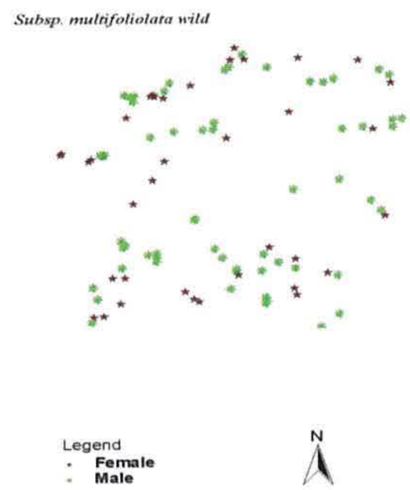

(Plot size = 11.70 Hectares)

Plate 4. 2: Scatter maps showing the assessed male and female trees of the three subspecies of *Sclerocarya birrea*, 100 trees for each population (*note that the plots of variable sizes*)

Table 4. 3: Distribution pattern of *Sclerocarya* trees in Holili, Kiegea and Malinzanga villages for on farm and wild populations at each village

Site	Trees/m² [d]	Expected NND (m) [r_e]	Observed NND (m) [r_o]	Ratio [R]
Holili farm	0.000151	40.67	32.37 ± 2.45	0.80
Holili wild	0.001702	12.12	11.71 ± 0.77	0.97
Kiegea farm	0.002038	11.08	12.38 ± 0.90	1.12
Kiegea wild	0.001464	13.07	13.60 ± 1.09	1.04
Malinzanga farm	0.000170	38.34	35.23 ± 3.26	0.92
Malinzanga wild	0.000855	17.10	14.11 ± 1.17	0.82

**NND = nearest neighbor distance*

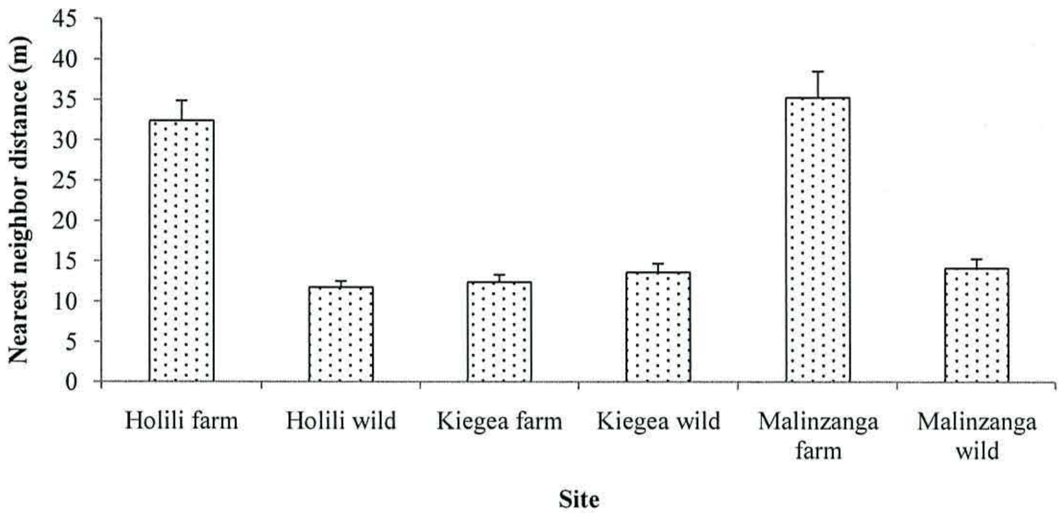

Figure 4. 1: Mean nearest neighbor distance between the village sites and between on farm and wild environmental conditions for *Sclerocarya birrea*

4.3.4 Population density by sex

The density of male and female *Sclerocarya birrea* in different populations and site conditions is presented in table 4.4. The density of male plants was significantly higher than that of females in all subspecies studied in both on-farm and wild populations hence the null hypothesis was rejected. The ratio of males to females was high for subspecies *caffra* (27 males: 10 females) in the wild and low for subspecies *multifoliolata* (12 males: 10 females) on farm condition. Subspecies *birrea* had more or less equal number of males in both environments (58 in the wild and 59 on farm) hence so were the female trees, but the others had more males in the wild environment compared to the on-farm environment.

Table 4. 4: Number of plants by sex and the ratio of males to 10 females for the three subspecies of *Sclerocarya birrea*

Subspecies	Sex	On farm and wild population combined		On farm and wild populations separated			
				on farm		*wild*	
		N	*M:10 F*	*N*	*M:10 F*	*N*	*M:10 F*
S. birrea	F	83	14	41	14	42	14
	M	117		59		58	
S. caffra	F	66	20	39	16	27	27
	M	134		61		73	
S. multifoliolata	F	84	14	45	12	39	16
	M	116		55		61	

- *N = number of plants;* M:*10*F *= ratio of number of male plants to ten female plants*

4.3.5. Size-structure variation between subspecies, environment and sex of *Sclerocarya birrea*

Diameter at breast height (dbh)

Diameter of trees varied significantly ($p<0.001$) between subspecies and environments (Table 4.5a). Mean diameter was 32.87 ± 0.67, 28.87 ± 0.70 and 39.96 ± 1.27 cm for *S. birrea*, *S. caffra* and *S. multifoliolata* respectively. For on farm populations, tree diameter ranged from 11 to 122 cm, while tree diameter for the wild populations ranged from 10 to 92 cm.

The mean dbh of the subspecies of *Sclerocarya birrea* on farm and wild population is shown in Table 4.5b. For both environments subspecies *multifoliolata* had the largest mean dbh. On farm trees for subspecies *multifoliolata* and *birrea* had larger mean diameter of 48.64 ± 1.88 cm and 37.56 ± 0.75 cm respectively compared to their respective wild trees which had 31.29 ± 1.19 cm and 28.18 ± 0.89 cm respectively. For subspecies *caffra*, wild trees had larger mean dbh (30.08 ± 0.84 cm) than on farm trees (27.66 ± 1.10 cm). Independent t-test showed significant difference ($p<0.001$) in tree diameter between on-farm and wild trees. The data gave a clue that populations with few stems per hectare had bigger dbh regardless of environment. Further analysis showed that most of the trees on farms were in the diameter class of 20 to 50 cm, while most tree in the wild fall in the diameter class of 10 and 40 cm (figure 4.4a-c). These figures also show that male individuals had larger diameter than the female trees in almost all diameter classes for each subspecies. Though there was a significant difference between male and female trees in terms of dbh in all subspecies ($p < 0.001$), t-test showed no significant difference between males and females when on-farm and wild populations were considered for each subspecies.

Table 4. 5a: Comparison of stand parameters between the different subspecies of *Sclerocarya birrea*

	S. birrea	*S. caffra*	*S. multifoliolata*
Tree diameter (cm±SE)	32.87±0.67	28.89±0.70	39.96±1.27
Branching height (m±SE)	2.73±0.07	2.69±0.07	2.61±0.08
Height to the top (m±SE)	7.02±0.16	7.35±0.20	9.06±0.20
Crown diameter (m±SE)	8.52±0.24	5.96±0.20	9.91±0.26

Table 4.5b: Comparison of stand parameters between on-farm and wild environments for all subspecies

Site	**Mean** ±SE			
	Diameter (cm)	Branching height (m)	Height to the top (m)	Crown diameter (m)
S. multifoliolata farm	48.64±1.88	2.91±0.12	10.07±0.27	10.67±0.34
S. multifoliolata wild	31.29±1.19	2.31±0.11	8.05±0.25	9.52±0.51
S. caffra farm	27.66±1.10	2.33±0.09	5.60±0.20	5.51±0.29
S. caffra wild	30.08±0.84	3.06±0.10	9.10±0.24	6.42±0.26
S. birrea farm	37.56±0.75	2.47±0.08	6.72±0.19	9.10±0.28
S. birrea wild	28.18±0.89	2.99±0.10	7.31±0.25	7.95±0.38

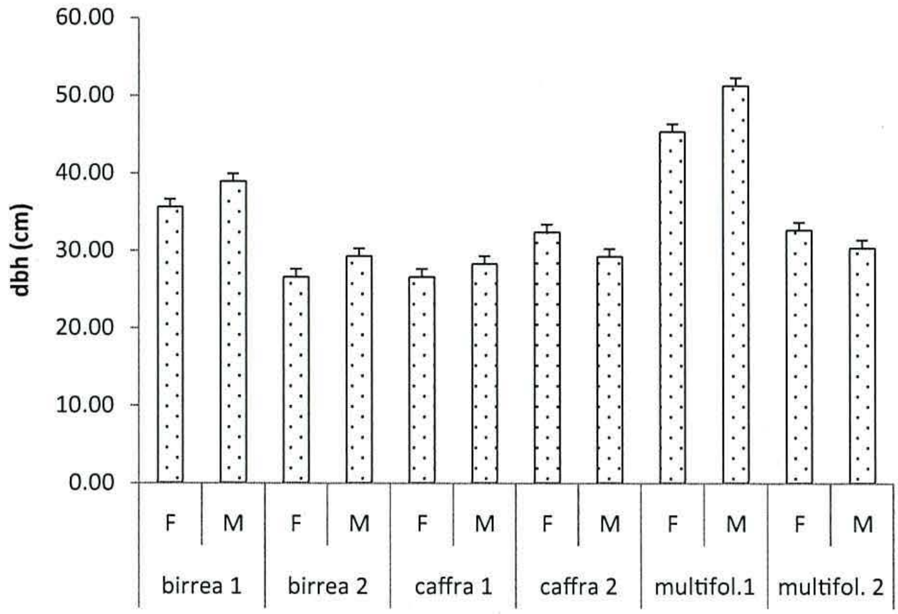

Figure 4. 2: Mean diameter at breast height (dbh) for on farm (1) and wild (2) female (F) and male (M) trees each of the three subspecies of *Sclerocarya birrea*

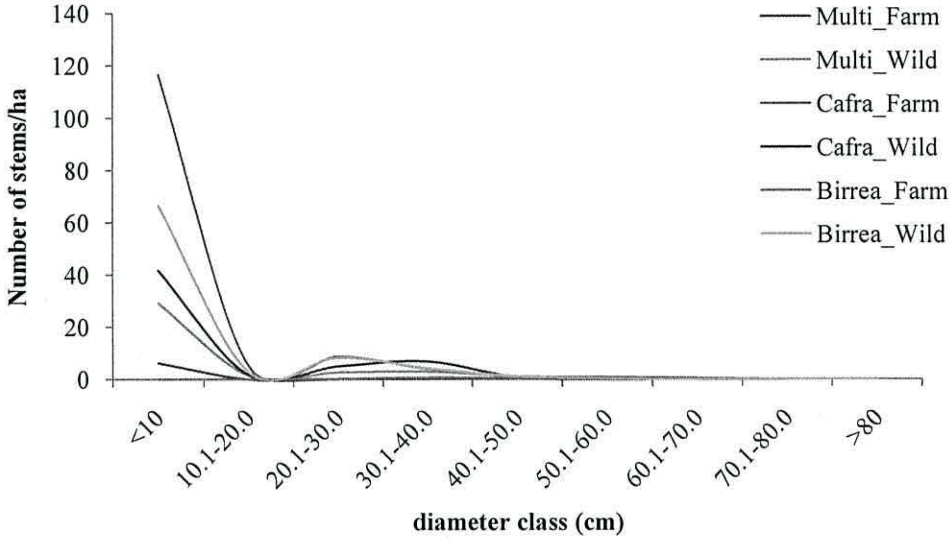

Figure 4. 3: Size - class distribution of the subspecies of *Sclerocarya birrea*

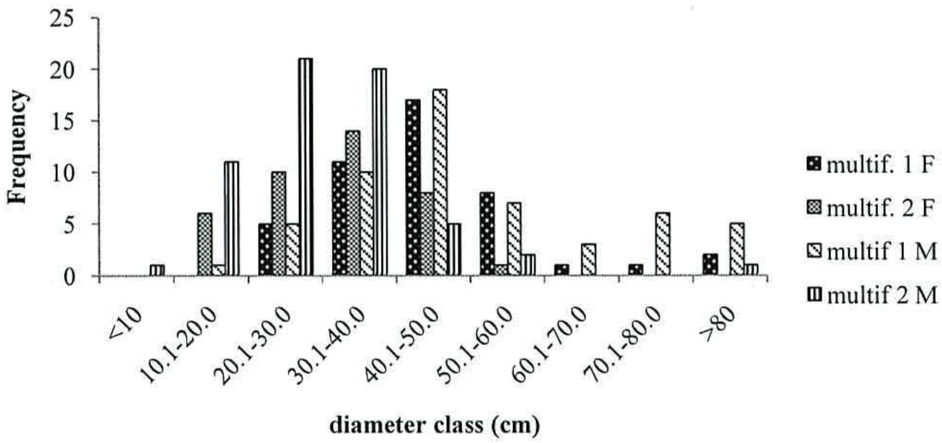

Figure 4. 4a: Comparison of diameter (cm) classes for males (M) and female (F) trees for subspecies *multifoliolata* on farm (1) and wild (2) populations

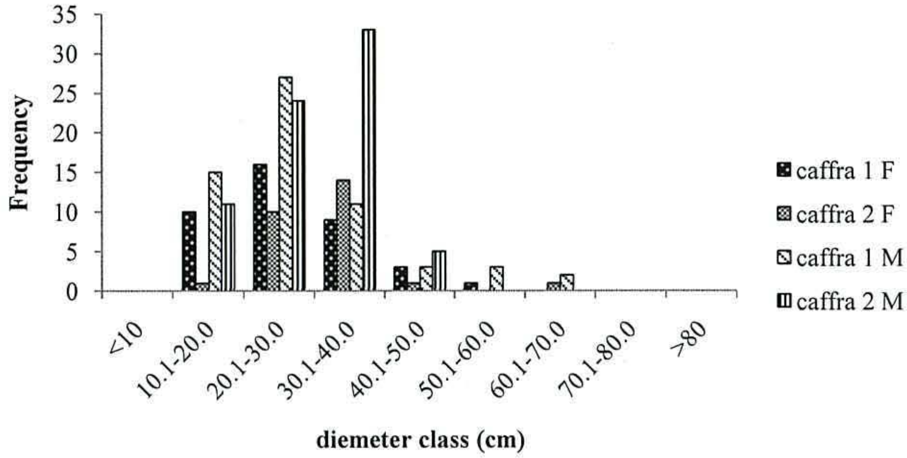

Figure 4.4b: Comparison of diameter classes in cm for males (M) and female (F) trees for subspecies *caffra* on farm (1) and wild (2) populations

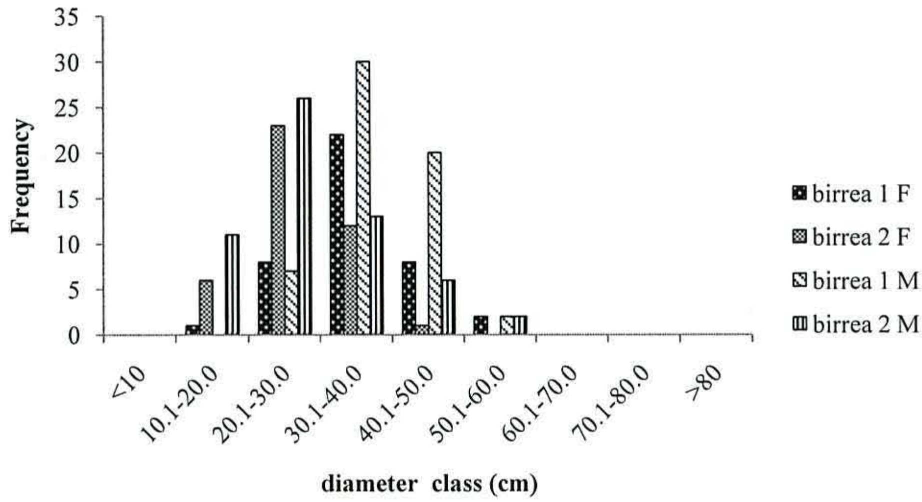

Figure 4.4c: Comparison of diameter (cm) classes for males (M) and female (F) trees for Subspecies *birrea* on farm (1) and wild (2) populations

Branching height

Mean branching height between on farm and wild populations is shown in Table 4.5b. Wild populations for *S. birrea* and *S. caffra* branched higher at a height of 2.99 ± 0.10 & 3.06 ± 0.10 m respectively, than their corresponding on farm populations which branched at 2.47 ± 0.08 & 2.33 ± 0.09 m respectively. For subspecies *multifoliolata* the on farm populations branching higher was height of 2.91 ± 0.12 m which was higher than those of the corresponding wild population which branched at = 2.31 ± 0.11 m. Comparing the three subspecies (Table 4.5b), *S. birrea* branched at the highest point (2.73 ± 0.07 m). The shortest branching height was observed in *S. multifoliolata* (2.61 ± 0.08 m). Independent t-test showed significant difference for the mean branching height between on farm and wild populations for each subspecies ($P<0.001$) while one way ANOVA showed no significant difference between the three subspecies.

An assessment of branching height by sex showed that with the exception of subspecies *birrea,* the female trees had longer clear boles than male trees (Figure 4.6). For *S. multifoliolata* and *S. caffra* females had larger mean branching height of 2.70 ± 0.14 and 2.75 ± 0.12 m respectively. For subspecies *birrea,* females had smaller mean branching height (2.65 ± 0.10 m) than males. The most dominant branching height class was 1.6 – 3.0 m followed by 3.1 - 4.5 m for all subspecies (Figure 4.5 a-c). However subspecies *multifoliolata* had trees in all branching height classes, while subspecies *birrea* had no any trees with branching height less than 1.5 m (Figure 4.5 a-c). Subspecies *caffra* also was having trees in all clear bole height classes but representation was irregular with missing sex in particular environment as seen in figure 4.5b.

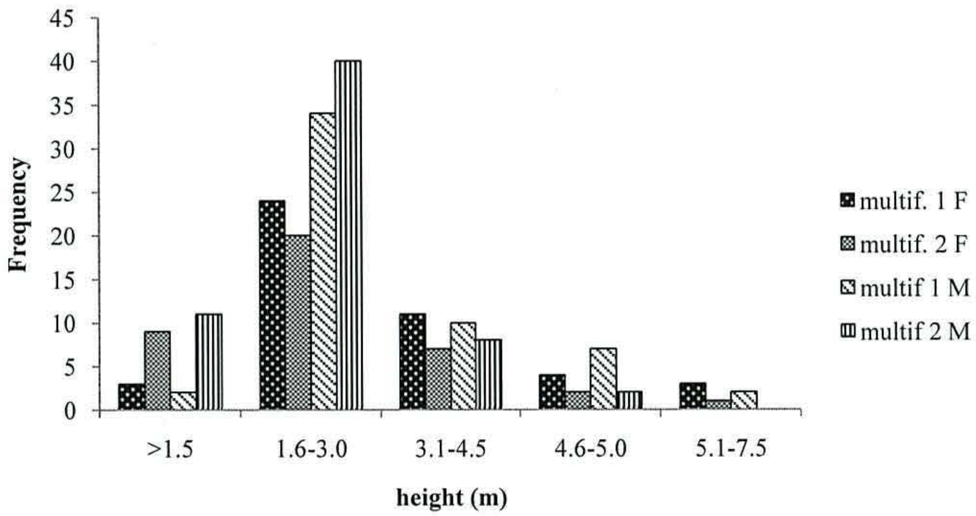

Figure 4.5a: Branching height (m) for male (M) and female (F) trees of subspecies *multifoliolata* on farm (1) and wild (2) populations

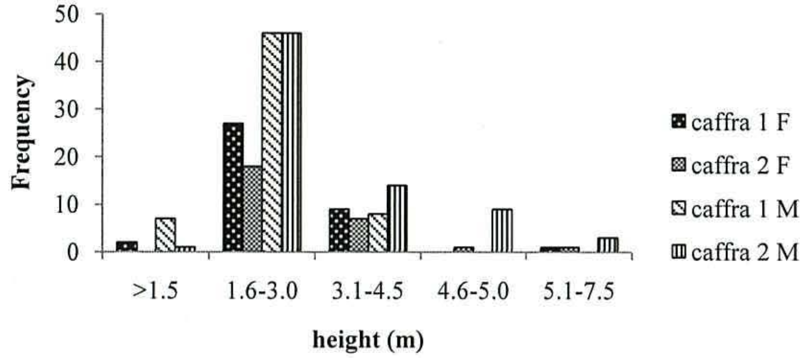

Figure 4.5b: Clear bole height (m) for male (M) and female (F) trees of subspecies *caffra* on farm (1) and wild (2) populations

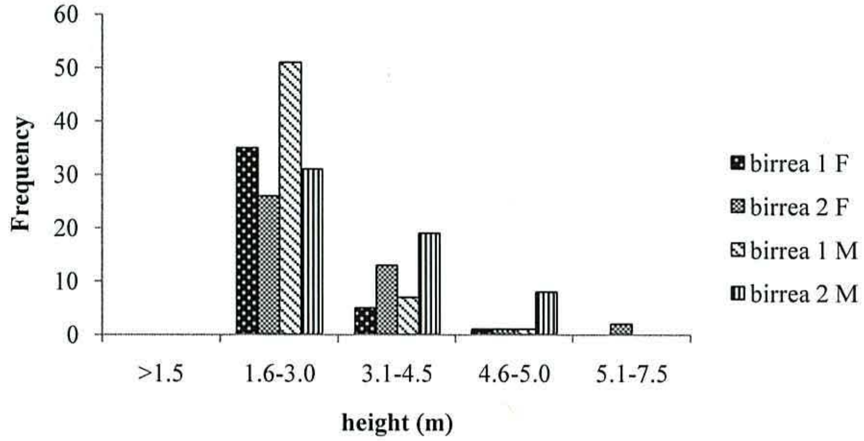

Figure 4.5c: Branching height (m) for male (M) and female (F) trees of subspecies *birrea* on farm (1) and wild (2) populations

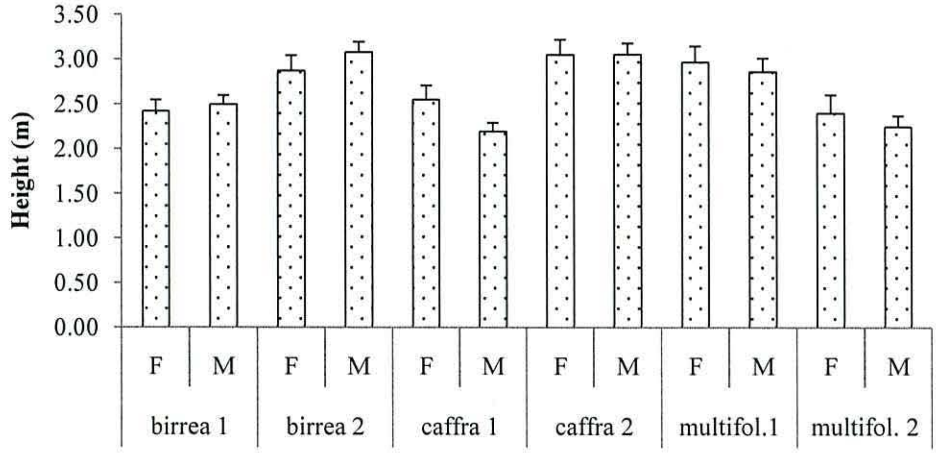

Figure 4. 6: Mean and error bars of branching height for males (M) and female (F) trees on farm (1) and in the wild (2) environments for the subspecies of *Sclerocarya birrea*

Total tree height

Overall for all subspecies most of the trees were in the range of 5-10 m tall (Figure 4.7a-c). For subsp. *multifoliolata* many trees had a height of 10 to 15 m followed by those between 15 and 20 m high (Figure 4.7a). For subspecies *caffra,* most trees were in the height class <5 m and 10 – 15 m (Figure 4.7b). Subspecies *birrea* had most of the trees in the height class 5-10 m and they were distributed more or less evenly by sex and environmental condition (figure 4.7c). The minimum and maximum height in meters was 2.5 & 16.3 for *S. birrea*; 3 & 15.8 for *S. caffra*; and 2 & 17.2 for *S. multifoliolata* respectively. Table 4.5 a-b shows the mean and standard error of mean height of the subspecies and the two environmental conditions; i.e. farm and wild conditions. Mean height was highest for *S. multifoliolata* (9.06 ± 0.20 m), followed by S. *caffra* (7.35 ± 0.20 m) while the least mean height was for *S. birrea* (7.02 ± 0.16 m). Wild population for subspecies *caffra* and *birrea* had larger mean tree height (9.10 ± 0.24 m and 7.31 ± 0.25 m respectively) than their respective on farm trees (5.60 ± 0.20 m and 6.72 ± 0.19 m respectively) while for subspecies *multifoliolata* the on farm trees were the ones with a larger mean height (10.07 ± 0.27 m) than the respective wild trees (8.05 ± 0.25 m). Using ANOVA and t-test we confirmed that statistically the differences between means of tree height were significant ($p<0.001$) between the subspecies and between the environments with the exception of subspecies *birrea.* For all subspecies and environments, male trees were taller than females although the difference was not significant. The mean height was 7.63 ± 0.18m and 7.92 ± 0.14m for female and male trees respectively.

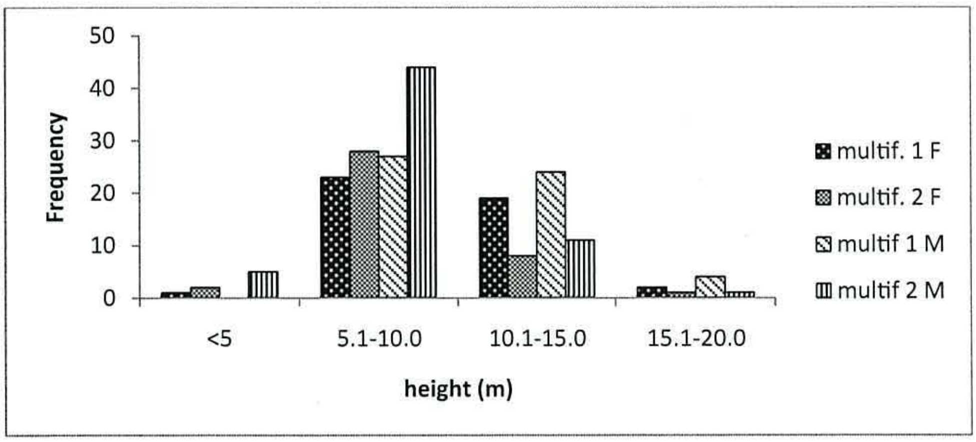

Figure 4.7a: Tree height (m) for male (M) and female (F) trees of subspecies *multifoliolata* on farm (1) and wild (2) populations

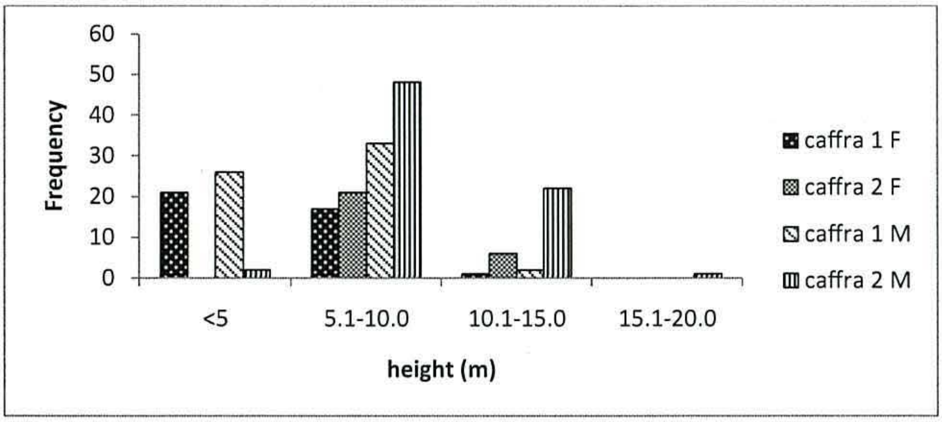

Figure 4.7b: Tree height (m) for male (M) and female (F) trees of subspecies *caffra* on farm (1) and wild (2) populations

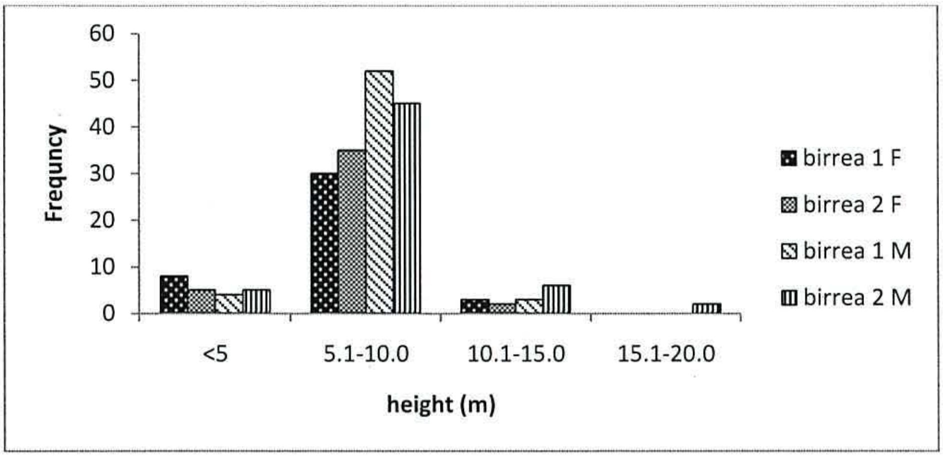

Figure 4.7c: Tree height (m) for male (M) and female (F) trees of subspecies *birrea* on farm (1) and wild (2) populations

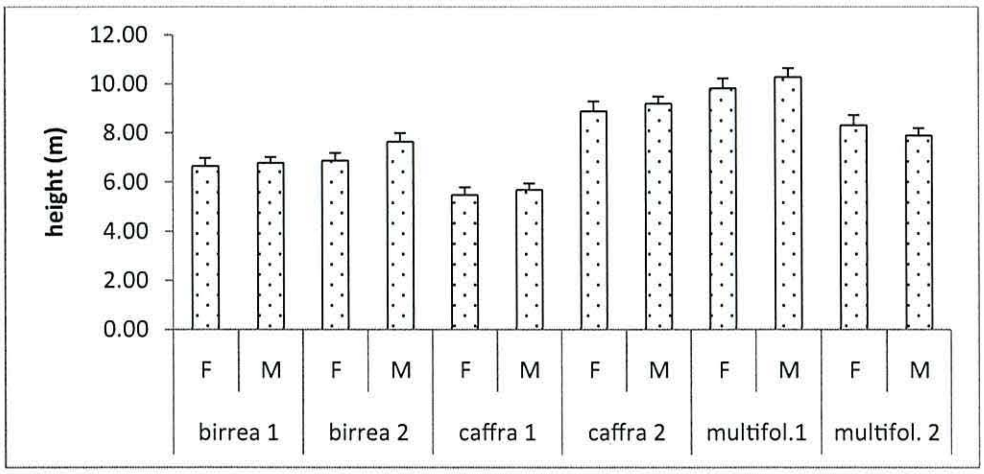

Figure 4.8: Mean and error bars of tree height for males (M) and female (F) trees on farm (1) and in the wild (2) environments for the subspecies of *Sclerocarya birrea*

Crown diameter

Most of the trees fell under crown diameter-class of 2-14 m, especially between 5-11m diameter (Figure 4.9 a-c). While subspecies *multifoliolata* had many trees with big (> 11 m) crown diameter, subspecies *caffra* had few trees with crown size in this category and while subspecies *caffra* had many trees with small (<5 m) crown diameter, subspecies *multifoliolata* had few trees in this category. The population of subspecies *birrea* had a more even distribution of crown diameter compared to the other subspecies with most of its trees falling in the class of 5-11 m crown diameter (Figure 4.10).

Mean crown diameter was 8.52 ± 0.24 m for subspecies *birrea*; 5.96 ± 0.20 m for subspecies *caffra*; and 9.91 ± 0.26 m for subspecies *multifoliolata* (Table 4.5a-b). From the tables it can be seen that *S. multifoliolata* trees had the biggest diameter while *S. caffra* had the smallest diameter. On farm population for subspecies *multifoliolata* and *birrea* had larger mean crown diameter (10.67 ± 0.34 m and 9.10 ± 0.28 m respectively) than the respective wild populations (9.52 ± 0.51 m and 7.95 ± 0.38 m respectively) while for subspecies *caffra* the wild trees were the ones with a larger mean crown diameter (6.42 ± 0.26 m) than their respective on farm trees (5.51 ± 0.29 m). Table 4.4 b and Figure 1.11 shows mean crown diameter for wild and on farm population and separates the values into male and female trees. ANOVA and independent t-test showed that statistically the differences in means of crown size were significant between the three subspecies ($p<0.001$) with *multifoliolata* having the biggest crown, but were not significant between on farm and wild environments. However; the means of crown size of male and female trees differed significantly between subspecies and within similar environmental condition ($p<0.001$). Females had small crown size than males except in wild populations of *S. caffra* and *S. multifoliolata* (Figure 4.11).

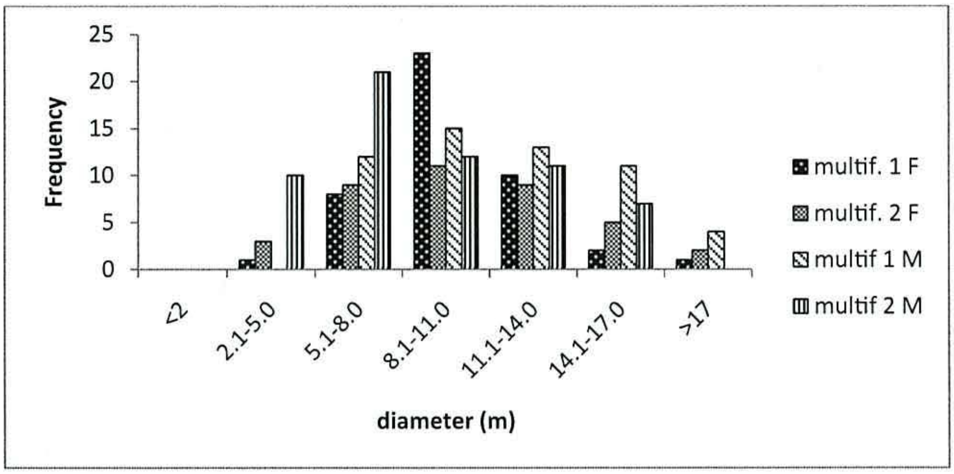

Figure 4. 9a: Crown diameter (m) for male (M) and female (F) trees of subspecies *multifoliolata* on farm (1) and wild (2) populations

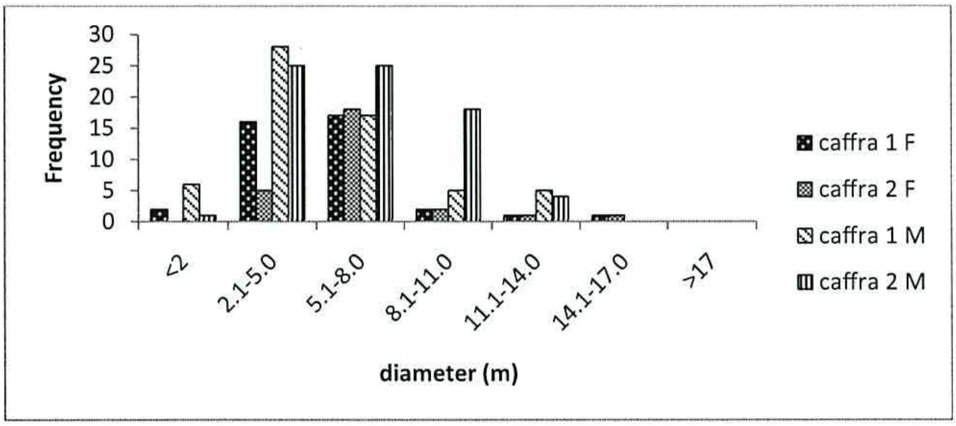

Figure 4.9b: Crown diameter (m) for male (M) and female (F) trees of subspecies *caffra* on farm (1) and wild (2) populations

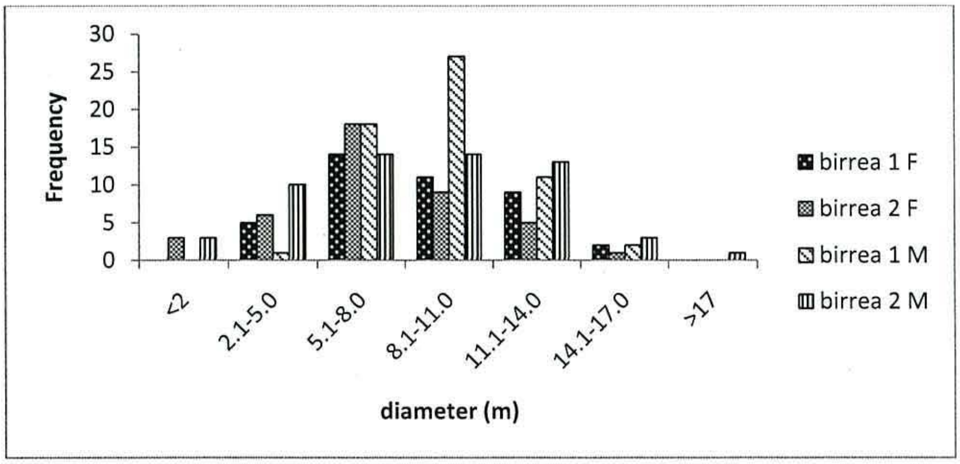

Figure 4.9c: Crown diameter (m) for male (M) and female (F) trees of subspecies *birrea* on farm (1) and wild (2) populations

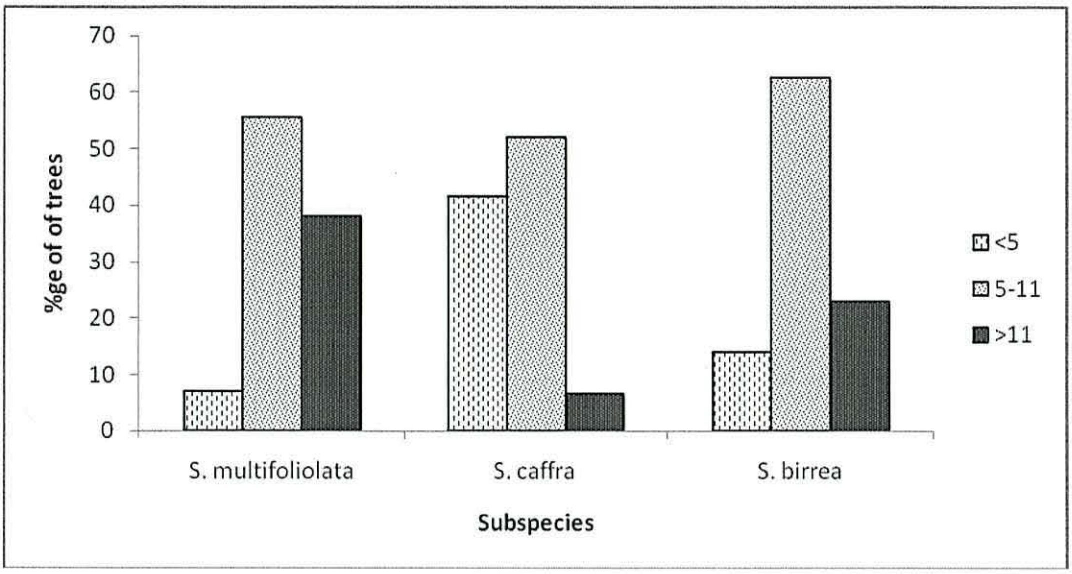

Figure 4. 10: Percentage of the subspecies of *Sclerocarya birrea* in different diameter classes

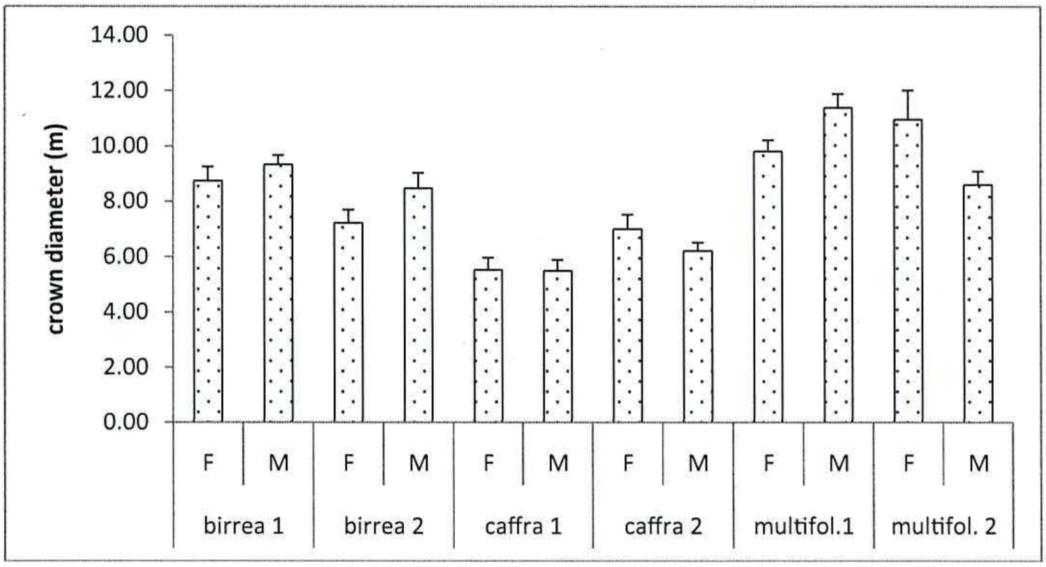

Figure 4. 4: Mean crown diameter and standard error of mean for males (M) and female (F) trees on farm (1) and in the wild (2) environments for the subspecies of *Sclerocarya birrea*

Relationship between altitude, tree diameter, branching height, height and crown diameter

Correlation ***(r)*** between one environmental parameter i.e. altitude and four tree parameters i.e. diameter, branching height, tree height and crown diameter showed a positive correlation (Table 4.6). All correlations were significant at $p < 0.001$. Interpretation of the correlation values were made using the Cohen (1988) criteria i.e. ***r***

= 0.10 - 0.29 = *small correlation*; ***r*** = 0.30 - 0.49 = *medium correlation*; and ***r*** = 0.50 - 1.00 = *large correlation.* Tree diameter had a strong correlation with tree height (***r*** = 0.60) and crown diameter (***r*** = 0.66). A strong correlation was also observed between tree height and crown diameter (***r*** = 0.53). Branching height showed a strong relationship with tree height (***r*** = 0.50).

Table 4. 6**:** Correlation of altitude, diameter, branching height, tree height and crown diameter for *Sclerocarya birrea*

		1	2	3	4
1. Diameter	r	-	0.29	0.60	0.66
	p	-	0.001	0.001	0.001
2. Branching height	r		-	0.50	0.24
	p		-	0.001	0.001
3. Tree height	r			-	0.53
	p			-	0.001
4. Crown diameter	r				-
	p				-

4.3.6 Natural regeneration of *Sclerocarya birrea*

Sclerocarya birrea regenerate both sexually and asexually through seeds and coppicing from stumps or sprouting from roots. Analysis of number of seedlings and saplings from seeds and vegetative regeneration (coppices and root sprouts) was done for each subspecies under both environmental conditions; on farm and wild conditions. With the exception of *S. caffra*, number of surviving seedlings and saplings was significantly higher under wild condition ($p < 0.001$) from both seeds and vegetative regeneration as shown in Table 4.7.

Table 4. 7**:** Seed and vegetative regeneration per hectare for *Sclerocarya birrea* for three different populations and two environmental conditions

Population	Environment	Coppice/Sprout Seedlings	Coppice/Sprout Saplings	Seed Seedlings	Seed Saplings	Mean total
S. birrea	on farm	7±3	2±1	3±2	7±3	22 ±5
	wild	92 ±30	58 ±22	17±8	8±2	175±14
S. caffra	on farm	217±44	75±14	83±22	42±17	417±92
	wild	50 ±29	33±22	25±14	8 ±3	116±16
S. multifoliolata	on farm	7 ±4	2 ±1	1±1	4±1	15±4
	wild	42±15	20±13	12±3	8±5	83±12

The on farm environment for subspecies *caffra* had exceptionally the most abundant number of seedlings and saplings (417± 92 seedlings and saplings ha^{-1}) while the on farm environment for subspecies *multifoliolata* had the least seedlings and saplings abundance (15 ± 4 plants ha^{-1}) (Table 4.7)

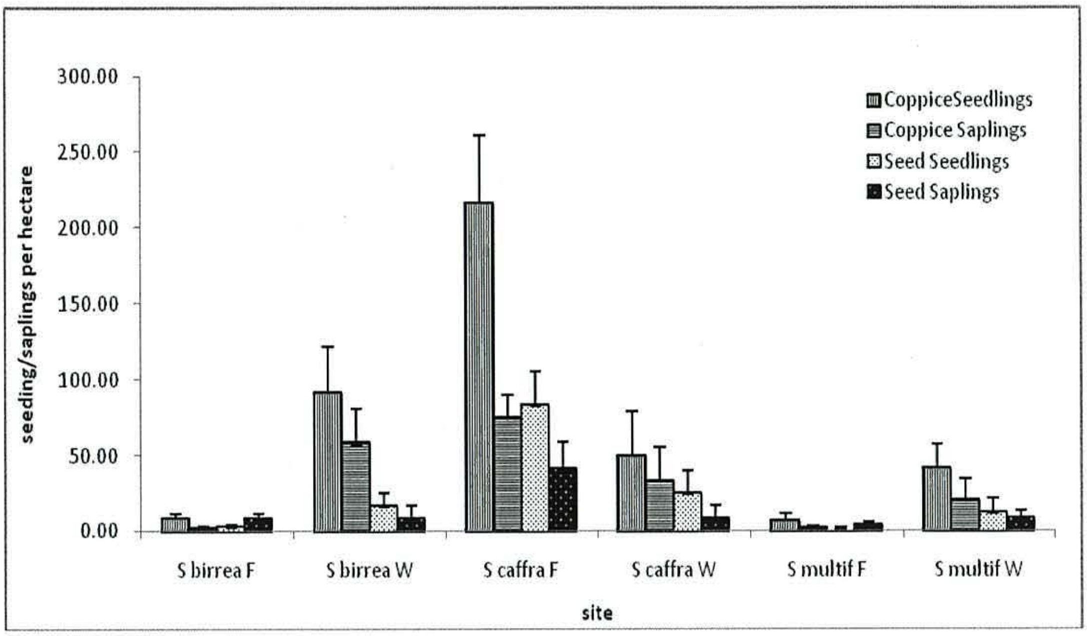

Figure 4. 5: Regeneration status of the subspecies of *Sclerocarya birrea* in numbers per hectare under on farm (F) and wild (W) environments.

Analysis to compare the modes of regeneration showed that vegetative seedlings and saplings were more than seedlings and saplings from seeds. The difference was similar for each subspecies with the exception of the on farm population for *S. birrea* where regeneration from seeds (11± 4) was slightly more than from vegetative sources (11 ± 3) and the difference was not significant (figure 4.15).

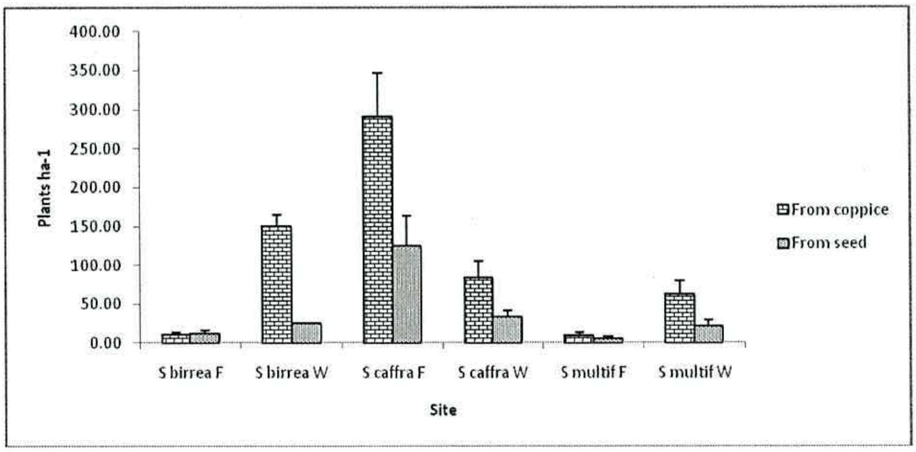

Figure 4. 6: Nature of natural regeneration for the subspecies of *Sclerocarya birrea* in each of on farm (F) and wild (W) environments

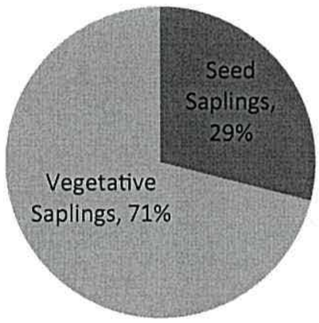

Figure 4. 7: Percentage of saplings originating from seeds and coppice/sprouts for *Sclerocarya birrea* in all subsecies

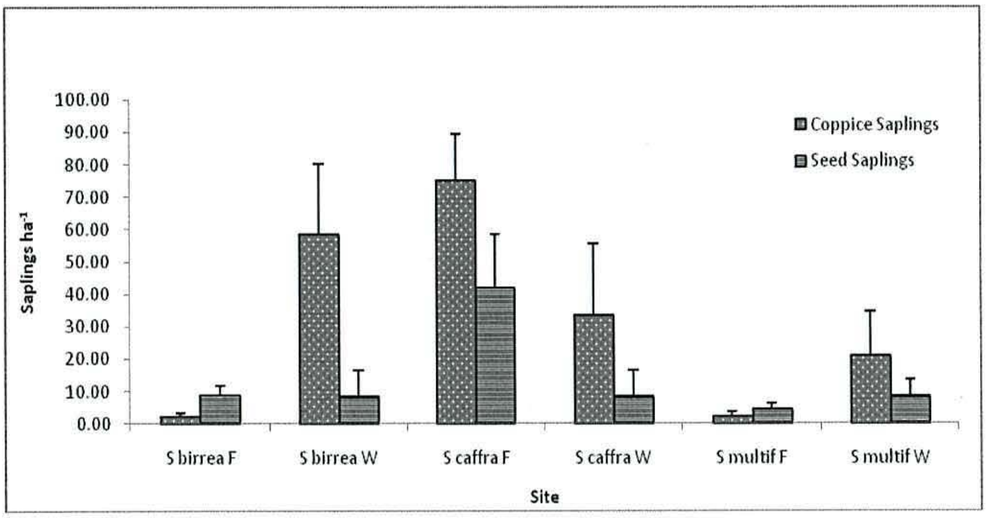

Figure 4. 8: Number of saplings per hectare by source (seeds or coppices) for each of the subspecies of *Sclerocarya birrea*

Results show that there were more saplings from vegetative than seed regeneration. This indicates that stump coppicing and root sprouting contributes to the sapling and eventually adult population than seedling from seeds. The source of 71 % of all saplings was vegetative from roots and stumps (Figure 4.14). When the subspecies were compared against each other, the pattern was the same (more coppice and root sprout saplings than seed saplings) with the exception of on farm population of *S. birrea* under where vegetative saplings and seed saplings were 2 ± 1 ha^{-1} and $8 \pm 3ha^{-1}$ respectively and *S. multifoliolata* where vegetative saplings and seed saplings were $2 \pm 1ha^{-1}$ and 4 ± 2 ha^{-1} respectively. Figure 4.15 compares the two sources of saplings for each subspecies and the two environmental conditions. It implies that for on farm environment seed sources perform better than coppices, with the exception of subspecies *caffra*.

4.3.7. Associated tree species of *Sclerocarya birrea*

Throughout the study sites 47 different species were found to be in association with *Sclerocarya birrea*. The abundance per hectare for each species is provided in Appendix III. *Acacia mellifera* ssp. *binderanum* which was associated with subspecies *multifoliolata* and *Dalbegia melanoxylon* (the African black wood) which was associated with subspecies *birrea*; were the most abundant species each with 126 trees ha^{-1}.

Species presence and absence pattern in the three populations; is presented in Table 4.8. The genus *Acacia* was represented by many species and was found in all the three study villages. There were no a single species found to be commonly associated with all the three subspecies. However some species were found to associate both with subspecies *multifoliolata* and *caffra* while others were associated with subspecies *caffra* and *birrea*. However there was no connectivity of distribution for *Acacia nigrescens* and *Acacia tortilis ssp. Tortilis.* The two species were found to associate with subspecies *multifoliolata* in the south and subspecies *birrea* north skipping subspecies *caffra* at the eastern-central part of the country.

The highest (4) and lowest (15) species richness for the associates was with subspecies *multifoliolata*. The populations of subspecies *multifoliolata* were the only ones which showed considerable difference in species richness between farm and wild conditions. For subspecies *birrea* and subspecies *caffra* species richness were more or less the same between the different environmental conditions (Table 4.9) where wild population of subsp *caffra* had a richness of 14 while all the other populations had a richness of 13. Simpson's Index (D) showed that the associates for on farm populations of *S. birrea* and *S. multifoliolata* were more diverse than the others with indices of 0.03 and 0.08 respectively. The populations with higher diversity had the least abundances (< 50 individuals per hectare) compared to the least diverse populations which had over 300 individuals per hectare. The wild population associated to subspecies *caffra* had the highest abundance with 668 individuals per hectare.

Table 4. 8: Distribution of species associated with *Sclerocarya birrea* in Southern, East-Central and Northern parts of Tanzania

Species	*S. multifoliolata*		*S. caffra*		*S. birrea*	
	Wild	**on farm**	**Wild**	**on farm**	**Wild**	**on farm**
Acacia brevispica				1		
Acacia gerrardii var. gerrardii			1	1		
Acacia mellifera ssp.melifera			1			
Acacia nigrescens	1				1	1
Acacia nilotica					1	1
Acacia senegal			1	1		1
Acacia senegal var. leiorhachis	1	1				
Acacia tortilis ssp. tortilis	1	1				1
Acacia xanthophloea	1					
Albizia amara			1	1	1	
Azanza garckeana					1	
Azadarachta indica	1					
Balanites aegyptiaca						1
Boscia salicifolia					1	1
Combretum apiculatum			1			
Combretum collinum ssp. binderanum			1			
Combretum fragans				1		
Combretum molle			1	1	1	1
Combretum zeyheri	1	1				
Combretum zeylanica			1	1		
Cordyla densiflora	1					
Crossopteryx febrifuga					1	1
Dalbergia melanoxylon			1	1	1	1
Delonix elata	1					
Euphorbia tirucalli	1					
Grewia microcarpa				1		
Lannea fulva					1	1
Lannea humilis					1	1
Lannea stuhlmannii						
Leucaena glauca				1		
Lonchocarpus capassa	1	1				
Maerua angolensis				1		
Markhamia lutea	1					
Markhamia obtusifolia			1			
Pteleopis myrtifolia			1	1		
Steganotaenia araliacea	1					
Sterculia africana					1	
Strychnos henningsii			1			
Strychnos mitis	1					
Terminalia brownii					1	1
Terminalia sericea			1	1		
Terminalia spinosa						1
Vitex payos	1					
Vitex strickeri			1			
Xeroderris stuhlmannii	1		1	1		
Zanthoxylum chalybeum			1			
Ziziphus mucronata				1		

Table 4. 9: Abundance and diversity of species associated with *Sclerocarya birrea* subspecies on farm (F) and wild (W) scenario

	S. caffra		*S. multifoliolata*		*S. birrea*	
	Wild	**on farm**	**Wild**	**on farm**	**Wild**	**on farm**
Stems per hectare	668	322	447	29	518	45
Simpson's Index (D)	0.11	0.12	0.11	0.03	0.12	0.08
Species Richness	14.00	13.00	15.00	4.00	13.00	13.00

4.4. Discussion

4.4.1. Soil properties

The soil classes; clay loam, sandy loam and loamy clay; observed across all the populations have been mentioned in other reports on soils found in *Sclerocarya birrea* habitats (Hall et al., 2002). The results shows low levels of organic matter content and exchangeable bases; with total nitrogen (N) ranging from 0.1 - 0.14% and are in line with other reports on soils under similar vegetations (Werger and Coetzee, 1978, Shackleton and Scholes, 2000, Hall *et al.,* 2002). Reports on studies from similar vegetations shows that top soil organic matter is about 1% and on average Ca2+ = 2076; Mg = 1.08; Potassium = 0.84 and sodium = 0.08 while total soil nitrogen is less than 0.1% as reported by Stromgaard (1989) and Chidumayo (1993). The absence of *Brachystegia* and *Julbernardia* species as associates of *Sclerocarya birrea* in this study may be related to the level of pH, slightly acidic and slightly alkaline (Chidumayo, 1993).

Contrary to expectation, soils in on-farm condition for subsp. *Multifoliolata* had more organic carbon than the respective wild condition. Farmers do not burn the farm residues in this area and perhaps the reason for the high level of organic carbon on farms. Farmers in Kiegea practices burning during land preparations while in Holili they don't burn but carryout brick curving/mining on farms subjecting the land to erosion by wind and runoff. Subsp. *birrea* and *multifoliolata* sites had soils which were slightly alkaline especially under the trees, and the results are in line with literature where it is pointed out that some *Sclerocarya* populations in Tanzania are found in alkaline soils (Hall *et al.*, 2002). The influence of *Sclerocarya* on soil nutrients was not observed and this may be because this study compared with soil samples taken 10 meters away from under the trees which were randomly distributed and rather close to each other.

4.4.2. Population density

The abundance of populations of subspecies *birrea* and *caffra* was more, up to twice, than that of subspecies *multifoliolata*. Subspecies *caffra* was the most abundant and unlike subspecies *birrea* and *multifoliolata*; its on farm population was abundant than wild population. The differences in abundance between the subspecies may relate to variability in agroecology and human influences but normally a combination of factors interplays to shape abundance and distribution of plants (Kikula, 1986; Zolho, 2005). Observations made during the field work noted that in Kiegea site wild fires occurred every season (Plate 4.3) unlike the other sites. But in Malinzanga farmers tend to remove *S. multifoliolata* on their farms for crop protection against wildlife and that the tree is also used for timber while in Holili brick making by farmers has led to severe land degradation on the farmlands (Chapter 3; Plate 4.4). The wildlife conflicts, fire incidents and brick curving may be reasons for the status of population density in the respective villages.

Plate 4. 3: Burnt forest at Kiegea where subsp. *caffra* was studied.

Plate 4. 4: Construction blocks mining in Holili, Tanzania

Elsewhere it is reported that moderate levels of fire has been found to be a useful management tool in woodland vegetation in Africa for it breaks seed dormancy (Banda *et al.*, 2006) and promotes tree growth and species diversity (Chidumayo, 1988; Frost, 1996). Where there is soil erosion; e.g. resulted from brick curving activities, there is also less trees in agroforestry systems (Bofa, 1999) while the intentional removal of trees in Malinzanga due to wildlife conflicts directly reduce tree populations on farms.

Compared to subspecies which are found in other countries, the abundance of the Tanzanian populations is high for both subspecies *birrea* (17 stems per hectare) and subspecies *caffra* (14.6 stems/ha) in the wild populations. The on farm population of subspecies *birrea* is low but that of subspecies *caffra* is exceptionally high (20.4 stems/ha), much more than its own wild populations and any of subspecies *caffra* recorded elsewhere across the species range for trees of >10cm dbh on farmlands. Hall *et al.* (2002) review of past inventory data including that by Lewis (1987), Scholes and Walker (1993), Maydell (1986), Marchal (1980) and Coetzee *et al.* (1979) shows that stand density, both wild and on farm; hardly exceeds 5 stems ha^{-1} and this includes trees of less than 10 cm diameter. A stand density of 1.5 trees ha^{-1} (including individuals of <1 cm diameter) was found by Nghitoolwa *et al.* (2003) during gender distribution survey for an on farm population in two neighbor villages in Namibia for subspecies *caffra*. Lewis (1987), Shackleton (1996, 1997), Bandeira *et al.* (1999) and Lombard *et al.* (2000) found different population densities per hectare, ranging from 7.5 to 37.5 from different areas in South Africa, Mozambique and Zambia, but their surveys included saplings or trees with less that dbh of 10 cm also for subspecies *caffra*. The abundance of *Sclerocarya birrea* subsp. *birrea* trees >13 cm in dbh in Benin was found to be 4.2 and 13.4 stems per hectare for on farm and wild populations respectively (Gouwakinnou *et al.,* 2009). Therefore Tanzania is not only harbouring the highest genetic diversity for *Sclerocarya birrea* (Kadu *et al.,* 2007), but for the first time this study reports that it has among the densest population across the species range, both on farmlands and in the wild.

Wild populations of subspecies *birrea* and *multifoliolata* were denser than the corresponding on farm population, which is what we hypothesized. But for subspecies *caffra* on farm population was denser that wild population. Therefore while it is obvious that farmers tend to retain just a few trees and weed out tree seedlings to give way for agriculture (Bofa, 1995; Fischer *et al.*, 2010; Bayala *et al.*, 2010), our results suggests that it is not always necessarily so. Farmers in Kiegea were able to retain most of S. *caffra* on their farms alongside their cultivated crops; abundance was high on farms than in the wild. The results for subspecies *birrea* and *multifoliolata*, but not *caffra*; are similar with the ones reported by Gouwakinnou *et al.* (2009) from Benin who found 10x more abundance in the wild population. Our results which showed high abundance for subspecies *caffra* on farm population may be used as a good indicator that domestication of the species as an agroforestry component is feasible. Farmers in this site do not use inorganic fertilizers implying that they might be retaining the marula trees on their farms because they improve crop yield. However further assessments on its tree-crop interaction is important to obtain empirical evidence on influence of marula on yield of intercrops as well as types of intercrops and optimum spacing.

At all levels there were more males than females. This is contrary to what have been reported for subspecies *caffra* and *birrea* in other countries where there are more females than males (DFID, 2003; Ngiitolwa *et al.*, 2003; Gouwakinnou *et al.,* 2009). To suggest that the sex ratio disparity is a result of human selection pressure may not be accurate because *firstly,* for Tanzania regeneration of the trees is 100% natural both on farmers' fields and in the wild, no farmer is reported to have planted the tree throughout the three study areas. *Secondly,* the high ratio of male to female trees is observed for both farmland and wild populations. Therefore the observed male trees biasness may be due physiological and environmental reasons, although the information in this study is not adequate enough to conclude. Some studies have suggested that for the resulting seed embryo to be female more pollens are needed to fertilize the ovaries (Stehlik *et al.,* 2006; 2007; 2008). The more the concentration of pollen deposited onto a female flower the more likely the resulting offspring will be a female. Therefore for expected offspring to be females, the maternal parent needs a couple of male plants around it and in close proximity to intensify pollen volume deposited on ovaries. If this mechanism applies to *Sclerocarya birrea,* the observed male to female density ratio favours not only availability of pollen supply for improved fruiting but also more female offsprings to be produced in the next few generations.

4.4.3 Distribution pattern

All the populations were observed to be randomly distributed with $\boldsymbol{R}$ values close to 1.0, meaning that the observed distribution (r_o) was close to the expected distribution (r_e) as $\boldsymbol{R}$ is the ratio between the two ($\boldsymbol{R} = r_o/r_e$). Given that the areas were different in size hence differences in density, the randomness is due to the values between pair trees making up a significant portion of the total population (Cottam and Curtis, 1956). This is possible because most of the values can be duplicates due to paired neighbors being neighbor to each other and making a significant portion of the total population. This implies that even if some of the populations occupied a much bigger area compared to the others, the trees were close to each other and therefore the empty spaces within the plots have no effect on the nearest neighbor distance (Okia, 2010). Since both wild and on farm populations showed random distribution it indicates that human activities have limited influence on the species distribution.

4.4.4 Size Structure

Subspecies *multifoliolata* had the biggest trees in terms of diameter, height and crown size followed by subspecies *birrea* and therefore subspecies *caffra* was the smallest. While the reason for this may be genetical there was a notable observation of incidents of seasonal fires in Kiegea where subspecies *caffra* occurs which could be affecting its growth. Fire, depending on frequency and intensity, tends to inhibit growth of woodland trees (Chidumayo, 1988; Zolho, 2005).

For subspecies *birrea* and *multifoliolata*, on farm trees had bigger diameter, height and crown diameter than wild trees and for subspecies *caffra* the situation was opposite. While on farm trees are expected to be bigger because of the care they receive through weeding and fertilization (McHardy, 2003; Leakey *et al*., 2005), our findings suggest that intraspecific competition may also influence on size of the trees. This is because the trees were bigger where the population was less dense as evidenced by on farm trees for subspecies *caffra* which were the smallest in size and densest of all the populations. Gouwakinnou *et al*., (2009) found that on farm subspecies *birrea* trees in Benin had 2x bigger dbh than wild trees which were more 10x denser than on farm trees. It is however important to note that the sizes of the trees could be influenced by their age which was unknown in this study.

Across all the subspecies and environments male trees were bigger than female trees. There is no a previous study which has assessed the differences in size between male and female *Sclerocarya* trees. However it is known that female plants spend a lot of food reserves for reproduction while for male trees such reserves are available for growth (Correia & Barradas, 2000; Wheelwright & Logan, 2004; Guangxiu, 2009; Varga & Kytöviita, 2010). This may explain the differences although long term and wider coverage studies particular to *S, birrea* are necessary to make a concrete conclusion.

With the exception of subsp. *multifoliolata*, branching height for on farm trees was lower regardless of sex. It appears that farmers do not prune lower branches probably for the tree to provide good shade. Low-level branches enable the crown to cast shade in a wider space for use by people while having lunch or rest during farming or when they are outside their houses at home (Plate 4.5). However farmers in the site where subsp. *multifoliolata* is found are close to Ruaha National Park and tend to dislike trees on farms in order to avoid wildlife crop raiders; farmers in the sites for subsp. *birrea* and *caffra* mentioned shade as among the top uses of *Sclerocarya* (Chapter 3), thus probably the differences in branching height for on farm trees. They therefore tend to prune or even remove the *Sclerocarya* trees to destruct movement of animals from tree to tree especially monkeys and therefore probably the observed high branching height. Pruning of agroforestry trees is also reported to improve yield of associated crops (Bayala *et al.*, 2002) although the impacts on yield are specific requiring assessment of each particular species and locality (Teklehaimanot, 2008).

Plate 4. 5: Using a subsp *birrea* tree as shade during interviews

On the other hand the higher branching height in the wild may be due to presence of other trees and a dense population status. Competition for light forces trees to develop a higher crown so as to capture light (*Osada et al.*, 2004). The species light requirements may also be the reason for why crown size was the only parameter with reasonable correlation (0.412, $p<0.001$) with elevation. Bush fires may as well influence availability of lower branches for wild populations due to frequent burning, severely damaging lower branches and eventually removing them. Less low branches and higher crowns opens up light to the underground eventually promoting growth of herbaceous vegetation which is suitable for burning and a reason for frequent fires (Mapaure and Campbell, 2002; Ribeiro *et al.*, 2008). This is in line with the findings of the current study since wild populations of subspecies *caffra* had the highest branching height (3.06 ± 0.10 m), hence few low branches, and it is the only study area where fires were frequent.

4.4.5. Regeneration

Subspecies *caffra* populations showed the highest regeneration both from seeds and vegetative means compared to subspecies *birrea* and *multifoliolata*. This difference in regeneration vigour is directly proportional to the abundance of parent stock. In areas where there were more adult trees per hectare regeneration was also high. Therefore with the exception of the site for subspecies *caffra*, regeneration was higher in the wild environment for both subspecies *birrea* and *multifoliolata* relative to the on farm environment. Several to hundreds of seeds were observed under mother trees but almost all of them did not survive to the next year due to mortality. The cause of mortality on farm seedlings is mainly tillage or intentional removal as farmers' reaction to the lack of legal ownership rights over mature trees. Mild fires could influence regeneration by breaking the hard marula seed nut as well as damaging of roots although this needs a long term monitoring study.

There was more regeneration from coppices than seeds. *Sclerocarya birrea* seeds are enclosed in a very hard shell which needs to be broken for germination to occur. However under mother trees there were many seedlings from seeds. Those seedlings on farms dies from tillage and probably those in the wild do not survive competition and fire. Vegetative seedlings have well developed root system than seedlings from seeds; therefore they grow fast and can better re-grow after damage by fire or browse. The influence of fire on germination of *Sclerocarya* seeds sounds complex and needs to be studied because fire can help opening up the nut shell or it can kill the seeds or very young seedlings. However several factors are reported to influence survival and proliferation of young plants in African vegetations. Seeds and seedlings suffer high rates of mortality from various environmental problems such as grazing animals, fires, uprooting during farming, fungi, insect pests and diseases. Janzane and Yanes (1991) reports that on tropical mainland especially in the dry forests, more than 90% of all tree species have more than 50% of their seeds killed by allelopathy, predators or fruit fungi between fruit set and seed germination. After germination, while young the seedling will need to survive destruction from fire and grazing animals. To be able to do this it needs a strong underground food reserve to enable vigorous resprouting when favourable conditions returns. Under these conditions saplings are better equipped due to well developed root systems of the parent tree.

A peculiar trend was observed for on farm populations of subspecies *birrea* and *multifoliolata* succession of seedlings to saplings generation. The population of saplings from seeds was four times higher than that of their respective seedlings. A normal population structure is the one which shows an increasing continuum of abundance from seedling through saplings to adult size classes (Mwang'ingo *et al.*, 2002; Enquist and Niklas 2001; Rubin *et al.*, 2006). The observed situation in this study is perhaps due to low survival of seedlings plus the longer time spent by the marula trees at the sapling state probably due to disturbances from browsing and tillage. The contribution to mature stand of *marula* was more from coppice regeneration because the abundance of coppice saplings was higher than seed saplings. This is also attributed to the higher capacity of reserving food in the roots compared to seedlings fresh from seeds. Saplings have an ability to re-sprout and grow faster as well as manage some competition from other young stand generation. Some suggestions for improved survival of seedlings and their eventual recruitment to sapling stage have been made by Hall *et al.*, 2002. Their suggestion include (i) uproot some seedlings to leave a few required and in accordance to spacing that will avoid competition; (ii) construction of water harvesting structures around seedlings; (iii) offering protection from browsing animals for example by fencing; and (iv) weeding to reduce competition and disease contamination from unwanted vegetation.

According to Mwang'ingo *et al.* (2002); Enquist and Niklas (2001); Rubin *et al.* (2006); Lehmann *et al.* (2009) who pointed out that a stable population is characterized by a smooth decrease in the number of individuals from the smaller to large size classes, with the intermediate class being well represented; the *Sclerocarya birrea* populations are stable and self maintaining. But care must be taken in future to rescue the tree from local disappearance because this is a prospective new crop candidate for exploitation Tanzania.

4.4.6 Associated vegetation

Populations studied were located north towards the Sudano region, south towards the Zambezian region and central probably the interface of the Sudano-Zambezian vegetation regions. Species associates were different between the north and south location, but associates of subspecies *caffra* comprised of a mixture of associates of subspecies *birrea* and *multifoliolata*.

Out of the 16 species identified as associates of *birrea* in the north, 8 of them appear in the compiled list of associates of *birrea* in relation to drainage by Hall *et al.* (2002). The species are *Acacia nilotica, Albizia amara, Combretum molle, Balanites egyptiaca,* *Boscia salicifolia, Dalbegia melanoxylon, Lannea humillis* and *Terminalia brownii*. Associates of subspecies *caffra* identified in the southern site were 23 whereby 7 of them are listed in the compilation by Hall *et al.*, 2002. Also five species associated with subspecies *multifoliolata* in this study are known to be associates with subspecies *caffra* according to Hall *et al.* (2002). These are *Acacia nigrescens, Acacia tortolis, Lonchocarpus capassa, Xeroderris Stuhmanii* and *Combretum zeyheri*. Two associate species of *multifoliolata, Combretum zeyheri* and *Lannea humilis,* in this study are found in the compilation by Hall *et al.*, 2002. Sharing of associates between the subspecies suggests a possibility of the species sharing habitats in Tanzania indicating a potential for exceptionally high genetic diversity. Kadu *et al.* (2006) found genetically distant characteristics between geographically proximate trees in Tanzania, more than in any of the other six countries he collected material for analysis. Conservation and management efforts need to be improved in Tanzania since it may be a source of important and unique genotype for domestication and ex situ conservation in gene banks.

Activities in this study involved intensive labour. Although it come up with interesting findings, it would be even better if for instance the data on soils and crown sizes was related to performance of agricultural crops, other plants/trees and important soil organisms under the marula crowns. However it is important to note that abundance of the trees on farms can be higher than in the wild only that its implication on crop performance needs to be established. Currently there are more male than female trees. Although it is possible for the ratio to be dynamically balanced by nature, grafting may be used where farmers wish to boost the female populations for instance for the purpose of fruit production.

CHAPTER FIVE: YIELD, PHENOTYPIC CHARACTERISTICS OF FRUITS AND PHENOLOGY OF *SCLEROCARYA BIRREA* IN TANZANIA

5.1 Introduction

5.1.1 Background

Sclerocarya birrea is a prime species for commercialisation in sub Sahara Africa (Teklehaimanot, 2005; 2008), and also outside of Africa (Hillman *et al.,* 2008). Good yield and appearance are among important factors in fruit trade to ensure supply to markets and fulfil consumers' desire for properties such as size, weight and texture (Seymour *et al.,* 2002). Various factors are said to affect fruit properties and yield performance of trees in dry areas. Some of the factors are soil water and nutrient availability, herbivory, competition and fire (Bofa, 1999; Murray and Gill, 2001; Wolfe and Denton, 2001); pollination intensity and degree of isolation among trees (Waites & Ågren, 2004; Kunin, 1993; Ghazoul 2005; Elliot and Irwin, 2009); fruit biophysiological properties (Lawes *et al.,* 1990); genetic make-up (Tanksley, 2004); weather fluctuation (Ågren *et al.,* 2008); and domesticated vis-à-vis wild condition (Bofa, 1999; Shackleton *et al.,* 2003; Tanksley, 2004; Leakey *et al.,* 2005; Emanuel *et al.,* 2005; Hillman *et al.,* 2008). Also within trees, yield and properties of fruits can be affected by tree features such as height and DBH (Peters *et al.,* 1988; Leishman *et al.,* 1995, Wolfe and Denton, 2001; Shackleton *et al.,* 2003). Big trees provide good mechanical strength to support more and heavy fruits (Wolfe and Denton, 2001). Also a study by Leakey *et al.* (2005) found the weight of subspecies *caffra* fruits to be largely contributed by the flesh rather than kernel.

Despite the mounting interest in commercialisation of *Sclerocarya birrea*, Shackleton, (2003) warns that the data on rates of fruit production and fruit properties available for Marula remains scanty; much of it being anecdotal. Many are informal observations or records of one or two accessible trees, and do not represent a good sample. Quin (1959) reported a yield between 21,667 and 91,272 fruits from four trees in South Africa with an average weight of 550 kg per tree. In comparison, Shone (1979) reported on one tree from the same area as producing 9,601 fruits or 270 kg. In the drier areas of North western South Africa, and Botswana, Peters (1988) reported a yield of 2,000 fruits (one tree) and 36,550 fruits (11 trees) or 550 kg per tree. Lewis (1987) measured fruit yield over a single month from 111 trees in the Luangwa valley (Zambia), and reported a total 226,000 fruits, or just over 2,000 fruits per tree. A figure of approximately 70,000 fruits per tree, or 570 kg is provided by Roodt (1988). Walker (1989) reported a yield of 6,900 to 12,100 fruits per year from a single tree over five years from the Matobos in Zimbabwe. Holtzhausen *et al.* (1990) provide a figure of an average of one ton of fruit per tree. The ratio of number of fruits to mass of fruits differs widely between these reports, indicating either extremely wide differences in the mass of individual fruits, or relatively crude extrapolations of mass (Shackleton *et al.,* 2003).

However, the work by Lewis (1987); Shackleton *et al.* (2003); McHardy (2003) and Leakey *et al.* (2005) present clear scientific methodologies. Their work on subspecies *caffra* in South Africa and Namibia reports more yield and heavy fruits from on farm than wild environment. They attribute the findings to the influence of farmers' selection pressure which is based on preference for high productivity traits. Their findings are in line with Tanksley, (2004) who says that fruit from domesticated species often have been tremendously enlarged over that normally found in the progenitor wild species

Phenology is a terminology in plant biology which refers to the rhythm of biological events, the relationship between these events as well as with the surrounding biological and physical environment (Lieth, 1974, Maignan *et al.,* 2008). The events include the detailed timing and duration of leafing, flowering and fruiting. The timing of many of these events will relate to biotic factors such as resource availability, pollinator availability and competition, abundance of herbivores, suitable conditions for seed germination and establishment, human interventions e.g. pruning and fertilisation, and phylogenetic constraints (Mosquin 1971; Johnson 1992; van Schaik *et al.,* 1993; Murali & Sukumar 994; Wright & Calderón 1995, Bofa, 1999). Biotic factors have been suggested as affecting phenological synchronization between species within the same guild (Frankie *et al.,* 1974; Stiles 1977). Phenology is also affected by abiotic factors. Of these factors, most likely to affect phenological patterns include changes in water level stored by plants (Reich and Borchert, 1984; Borchert, 1994), seasonal variations in rainfall (Opler *et al.,* 1976), changes in temperature (Ashton *et al.,* 1988; Williams-Linera, 1997), photoperiod (Leopold, 1951; Tallak Nilsen and Huller, 1981; van Schaik, 1986; Rivera *et al.,* 2002), irradiance (Wright and van Schaik, 1994), sporadic climatic events (Sakai *et al.,* 1999), fire (Bofa, 1999); and temperature and photoperiod (Ratheke

& Lacey 1985; Badeck *et al.* 2004; Molau *et al.* 2005) of which the later, in temperate regions, are clearly seasonal (Vitasse *et al.,* 2009). Some studies however have suggested that plant phenology is principally constrained by phylogenetic membership or life form (Kochmer and Handel, 1986; Wright and Calderón, 1995). It means that phylogenetic constraints are stronger than local ecological factors, thus members of the same taxa should have similar phenological patterns regardless of geographical location (Kochmer and Handel, 1986).

The control of vegetative phenology in tropical trees is not well understood and is complex compared to that of temperate species. In dry forest trees for example, leaf abscission may be enhanced by advanced leaf age or increasing water stress. In this region, temperature and duration of daylight are not remarkably seasonal. The marked pattern is the variation between diurnal and nocturnal temperature rather than seasonal variation in temperature. However there is a seasonal pattern in rainfall and this has an influence in phenological events (Brearly *et al.,* 2007). Normally, it is impossible to dissect the effects of each of these variables because for instance most leaves are shed during the early dry season when leaves are also relatively old (Borchert *et al.,* 2002). In the dry tropics, the general view is that groundwater availability is the major environmental variable controlling canopy dynamics (Borchert, 1994; Eamus and Prior, 2001). For example, Lobo *et al.* (2003) reports that precipitation and soil water content regulates leaf flushing and abscission. However Fenner (1998) insists that biotic and abiotic factors selectively influence phenology of plants in specific ways.

Elucidation of phenological patterns relative to the prevailing climatic and other environmental conditions is essential for a full understanding of the functional aspects of trees (Bawa and Hadley, 1991) and prediction of the potential effects of climate change on vegetation (Singh and Kushwaha, 2005a). Huxley (1996) highlighted the scantiness of research concerning tree phenology in agroforestry systems, despite its potential impact on understorey crops. Similarly knowledge on reproductive phenology and pollination biology are basic elements that should be considered in the management and exploitation of plant species that offer non-timber products because they are important in development and implementation of management strategies (Salinas-Peba and Parra-Tabla, 2007, Nayak and Davidar, 2010).

In their review, Hall *et al.* (2002) briefly presented some previous work on the phenology of *Sclerocarya birrea* although the methods used are unclear and they are mostly old information on subspecies *caffra*. Shackleton *et al.* (2003) points out that most such studies on *Sclerocarya* are short-term mixing different levels of analysis: individual, population, and community, in attempting to describe complex, diverse, and irregular patterns. So far there are no studies which have attempted to compare the phenological events between its subspecies, sex of the trees, and the environments in which they occur, except McHardy (2003) who compares fruiting between populations of subspecies *caffra* found in rangelands and homesteads. For successful conservation and domestication efforts aimed at the species, elucidating this basic biological information remain vital.

Since the three subspecies of *Sclerocarya birrea* occur together in Tanzania, this study had an ideal opportunity for a concurrent monitoring, comparison and contrasting the phenological events using direct field material. The study also collected field data on fruit yield and assessed fruit properties in relation to the subspecies, land use, tree sizes and seasonal weather variation. The information contributes to the basic understanding as well as comparing and contrasting the three subspecies. Future domestication plans will benefit from this information as basic guidance for silvilculture, breeding and postharvest processes including marketing.

5.1.2 Objectives

The main objective of the present study was to assess and compare the phenology, fruit yield and fruit phenotypic characteristics between the three subspecies of *Sclerocarya birrea* in Tanzania. Specifically the objectives were:

- To assess fruit phenotypic characteristics and make comparison between the subspecies and environment
- To quantify and compare fruit yield per tree by subspecies and environment
- To assess and compare the annual cycle of phenological events attributed to *Sclerocarya birrea* with reference to the three subspecies, environment and gender

5.1.3 Hypothesis

- Phenotypic characteristics (fruit yield, size and weight) of *Sclerocarya birrea* fruits are not different between its three subspecies
- Land management practices on farms have no effect on fruit yield in terms of number of fruits produced per tree as well as size and weight of individual fruits
- The annual timing of phenological events is not different between the subspecies of *Sclerocarya birrea*
- Land husbandry practices have no effects on leafing, flowering and fruiting phenophases of *Sclerocarya birrea*
- There is no difference between the phenology of male and female trees of *Sclerocarya birrea*

5.2 Methodology

The study was conducted in three sites (Holili in Kilimanjaro region, Kiegea in Morogoro region and Malinzanga in Iringa region), each representing one subspecies of *Sclerocarya birrea*.

5.2.1 Materials and methods

5.2.1.1 Fruit phenotypic characterisation

Ten female trees from each land use for each subspecies were used to assess fruit phenotypic characteristics and yield per tree. From each of the ten female trees, 50 fruits were picked during peak fruit dropping for assessment of diameter and weight. Fallen fruits were usually plentiful beneath the tree crown, and so ripe, unblemished fruits were collected at random, sampling from 5 quadrants (10 fruits per quadrant), following the procedures described by *Leakey et al.* (2000) and used by Shackleton *et al.* (2003). Fruits from each tree were separately bagged and labelled. As soon as possible; usually the same day or 2-3 days later, the fresh fruits were weighed using an electronic balance. In the same period diameter of the fruits were measured in centimetres using Vernier callipers. With the exception of few, the *Sclerocarya* fruits are not perfectly roundish, so 3 diameters were taken for each fruit and an average was taken to be the mean diameter value.

5.2.1.2 Fruit yield

During fruit fall; fruits were picked up from under the ten trees and counted at irregular intervals of days depending on frequency of fall until the end of fruit fall. Data on fruit yield was collected for two seasons, 2007/08 and 2008/09. Although randomly selected, it was ensured that female trees assessed were at least 30 m away from the nearest female neighbour to avoid mixing of fruits.

5.2.1.3 Phenological assessment

Forty reproductive trees per subspecies or village were randomly selected and marked for assessment of phenology over 24-months period, making a total of 120 trees from the three subspecies. Ten trees were selected from each sex from each of the wild and on-farm populations. The respective tree diameter, total height, height to the first branch and crown diameter was measured and recorded. Both the onset and relative duration of leafing, flowering and fruiting phenophases was determined on the selected trees. Number of trees at various stages of leafing (e.g. bud break, flushing or shedding), flowering (e.g. peak flowering and dry flowers) and fruiting (e.g. green, mature and dropping fruits) were recorded. Table 5.1 shows the codes and the respective phenological parameters assessed. Associated monthly values for precipitation, minimum and maximum temperatures were obtained from nearest weather stations for a 24 month duration starting from January 2008 to December 2009. Any incidences of bush fires were also recorded. Data was collected from each tree at intervals of two weeks with the help of trained local assistants.

Table 5. 1: Codes and definition of phenological events

Code	Definition of phenologies		
	Leafing	***Flowering***	***Fruiting***
0	Leafless	No buds	Fruitless
1	Bud break	Opening buds	Early fruit setting
2	Flushing	Open flowers	Developing green fruits
3	New leaf	Peak flowering	Fully developed greenish fruits
4	Mature leaf	Age mixture of flowers	Peak maturation and dropping
5	Shedding	Dried flowers	End of fruit dropping

5.2.2 Data analysis

Data on weight, diameter of individual fruits and number of fruits per tree was analysed to obtain range, mean and standard error of mean using Minitab program which in turn was used to develop bar graphs using Excel program. Number of fruits per tree was also used to estimate fruit weight yield per tree by multiplying with the mean weight of individual fruits. Since fruit weight was not assessed in the 2008/09 season, fruit yield per tree for that year was estimated using the mean obtained in the previous season. One way ANOVA was done to assess the differences between means by subspecies while student t-test was used to assess the differences in means by land use (on farm and wild) conditions. Paired t-tests were used to compare number of fruits per tree between the two seasons, 2007/08 and 2008/09. Regression and/or correlation analysis was done to establish the relationship between the fruit properties and yield with tree size parameters (crown diameter, tree height and diameter at breast height).

Data collected for phenology was processed in excel to obtain percentages of trees under particular phenological activities for each month over the two years. Data was separated in 24 months datasets (using pivot tables) by subspecies, environment and sex of tree where the columns represented phenophase events taking place during leafing, flowering and fruiting and rows represented months. Then line graphs for each dataset were produced in such a way that for instance, phenophases under leafing (Table 5.1) for female trees of subspecies *multifoliolata* in the wild environment appeared together on one graph.

5.3 Results

5.3.1 Temporal and site variation in temperature and rainfall

Data on monthly rainfall and mean monthly temperature for the three sites in two years were obtained from a nearest weather station to each site. The weather data for the three study sites is shown in Figure 5.1. For Malinzanga site where subspecies *multifoliolata* was assessed it shows that during the two years, the pattern was similar where the months of May to September were the coldest with temperatures below 20°C. In terms of rainfall, the months of January and February 2008 received more rainfall, almost twice as much; than the rainfall received in the same months in 2009.

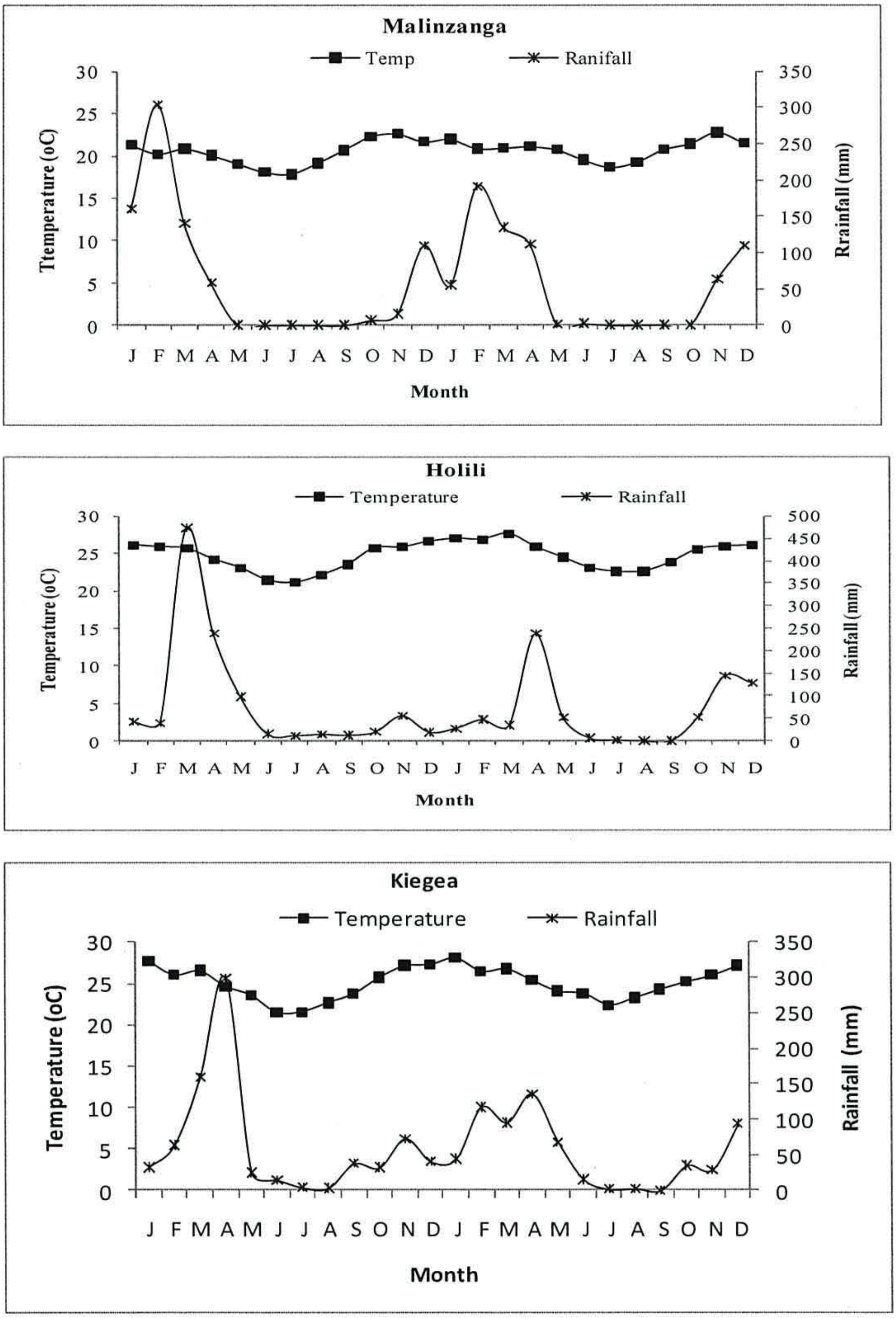

Figure 5. 1: Mean monthly temperature (^{o}C) and monthly total rainfall (mm) from January 2008 to December 2009 for the three study sites

The wet months were from November to April with the months of May to October receiving zero rainfall. The months with no rainfall were also the coldest months. For

Holili (subspecies *birrea*) and Kiegea (subspecies *caffra*) the rainfall and temperature patterns were the same. Temperatures were in most of the months above 24°C. In the two sites almost each of the dry months in 2008 recorded some amount of rainfall. The dry months were May to October in the two sites but Holili had a drier spell between January and February compared to Kiegea. In all sites there was a decline in rainfall in 2009, especially in the peak months of March and April.

5.3.2 Fruit phenotypic characteristics

5.3.2.1 Fruit weight

Results showed that the weight of fruits produced by subspecies *multifoliolata* were the heaviest with mean weight for an individual fruit of 28.941 ± 0.269 g. Mean weight for individual fruits of subspecies *birrea* and *caffra* was 25.71 ± 0.23 g and 24.01 ± 0.22 g respectively (figure 5.2). ANOVA showed that the differences between the means by subspecies was significant at $p < 0.001$ ($F = 107.60$; $\alpha = 0.001$; $DF = 2$).

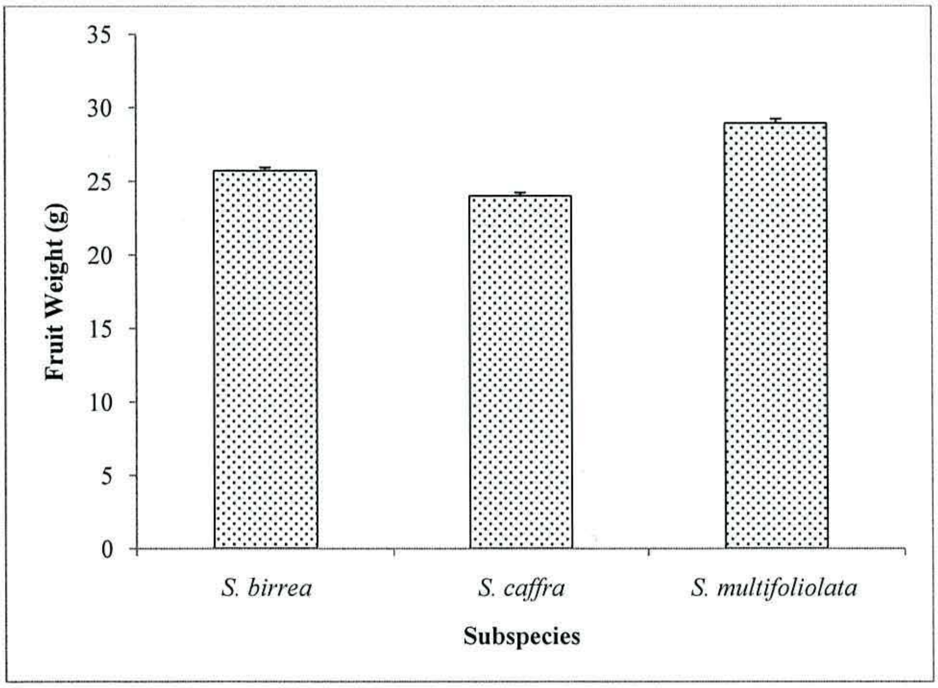

Figure 5. 2: Mean and error bars for fruit weight for the subspecies of *Sclerocarya birrea*

The results in Figure 5.3 show the mean weight and standard error of the mean for on farm and wild fruits of the three subspecies. Mean weight for on farm fruits of subspecies *multifoliolata* was 27.77 ± 0.61 g (range = 11.34 - 41.13 g) while those from the wild population had a mean weight of 30.11 ± 0.42 g (range = 12.80 - 47.70 g). Independent t-test showed that fruits from wild trees were significantly heavier than those from the on farm environment ($p < 0.001$, $t = 4.43$; DF = 498; 95% CI = -3.373 to -1.300).There was a slight difference between on farm and wild fruit weight for subspecies *caffra*. Figure 5.3 shows that mean weight for on farm fruits of this subspecies was 24.03 ± 0.33 g (range = 11.70 – 36.42 g) and mean weight for wild population fruits was 24.00 ± 0.29 g (range = 12.67 – 35.00 g). Independent t-test showed that the difference in the means was not significant ($t = 0.07$; $\alpha = 0.95$, DF = 498; 95% CI = -0.84 to 0.9) for subspecies *caffra*.

Mean weight of fruits of subspecies *birrea* indicates that fruits from on farm trees were heavier than fruits from trees in the wild environment (figure 5.3). Mean weight of fruits from on farm trees was 26.03 ± 0.33 (range = 14. 69 - 38.85 g) and for fruits from the wild population was 25.39 ± 0.24 g (range = 13.71 - 38.13 g. Independent t-test revealed no significant difference in weight between on farm and wild fruits ($t = 1.37$ $\alpha = 0.170$ DF = 498; 95% CI = -0.274 to 1.546).

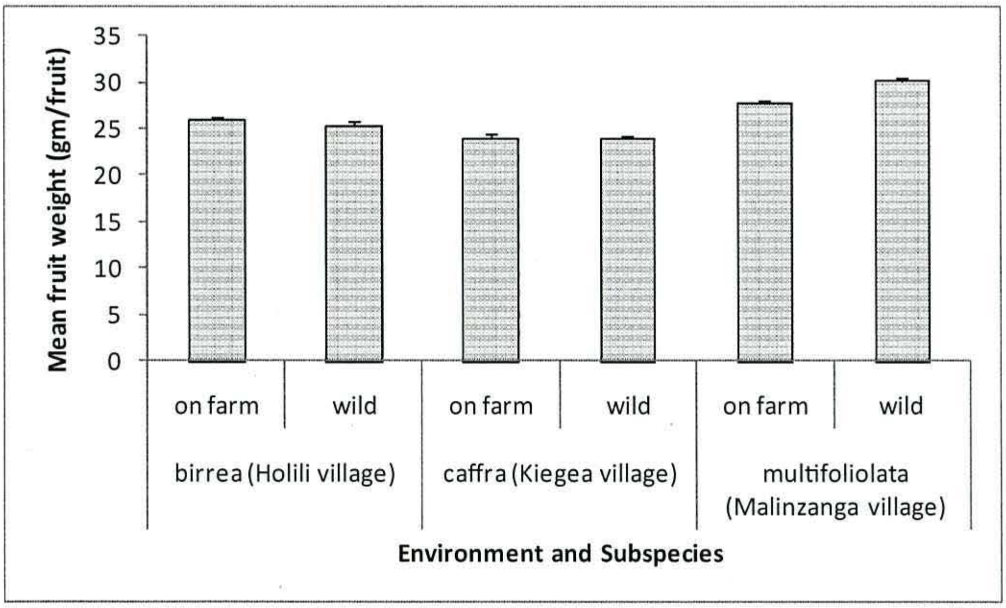

Figure 5. 3: Mean fruit weight and standard error for *Sclerocarya birrea* by subspecies and environment

5.3.2.2 Fruit diameter

Mean fruit diameter for subspecies *caffra* was the smallest (2.88 ± 0.013 cm) compared to mean fruit diameter for *multifoliolata* (3.20 ± 0.017 cm) and *birrea* (3.21 ± 0.017 cm) (figure 5.4). Analysis of the means using one way ANOVA showed the differences were significant at $p < 0.001$ ($F = 134.33$; $DF = 2$; $\alpha = 0.001$).

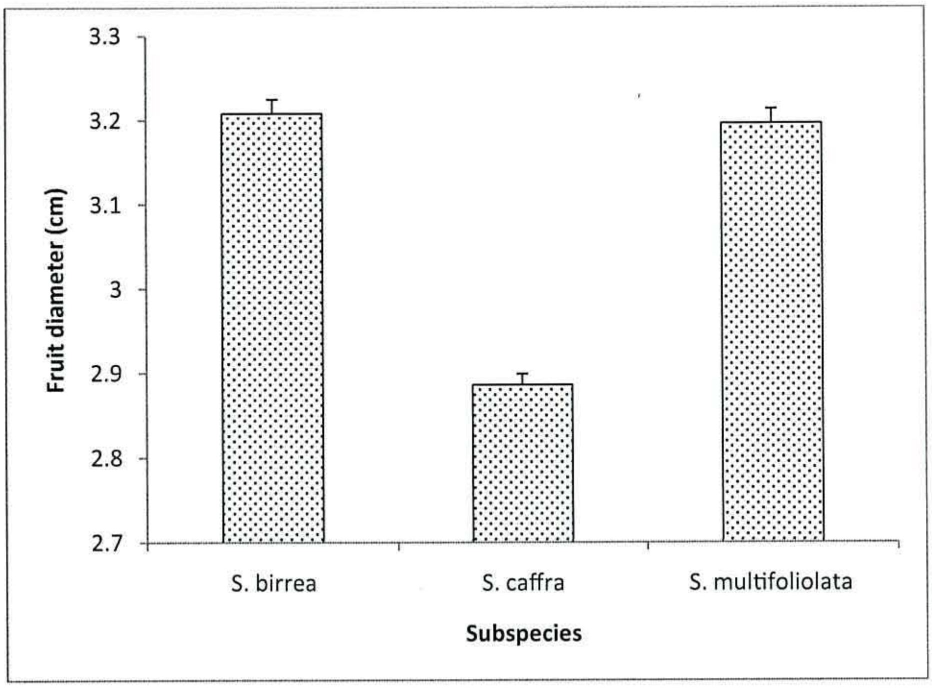

Figure 5. 4: Mean and error bars of fruit diameter for the subspecies of *Sclerocarya birrea*

Mean diameter and error bars for on farm and wild populations are presented in Figure 5.5. For subspecies *multifoliolata* mean diameter of fruits from on farm population was 3.12 ± 0.03 cm (range = 2.33 - 4.20 cm) and that of fruits from the wild population was 3.27 ± 0.02 cm (range = 2.50 - 3.93 cm). Independent t-test showed that for subspecies *multifoliolata*, fruits from the on farm population were significantly smaller ($p \leq 0.001$) than those from trees in the wild environment ($t = -4.46$; $\alpha = 0.001$; $DF = 498$; 95% CI = -0.2169 to -0.0842.).

For subspecies *caffra* mean diameter of fruits from on farm population was 2.85 ± 0.02 cm (range = 2.26 - 3.47 cm) while mean diameter for fruits from trees in the wild population was 2.92 ± 0.02 cm (range = 2.17 - 3.52 cm). Independent t-test showed that the difference between the means was significant at $p < 0.05$ ($t = -2.51$; $\alpha = 0.012$; DF =

498; 95% CI = -0.1117 to -0.0136), with wild fruits bigger than on farm fruits. For subspecies *birrea* mean fruit diameter for fruits from on farm trees was 3.29 ± 0.03 (range = 2.50 - 4.17 cm) while the mean diameter of fruits from wild trees was 3.12 ± 0.02 cm (range = 2.63 - 3.90 cm). Independent t-test showed that the differences in the means was significant ($p \leq 0.001$) with wild fruits smaller than on farm fruits ($t = 5.20$; $\alpha = 0.001$; DF = 498; 95% CI = 0.1079 to 0.2388).

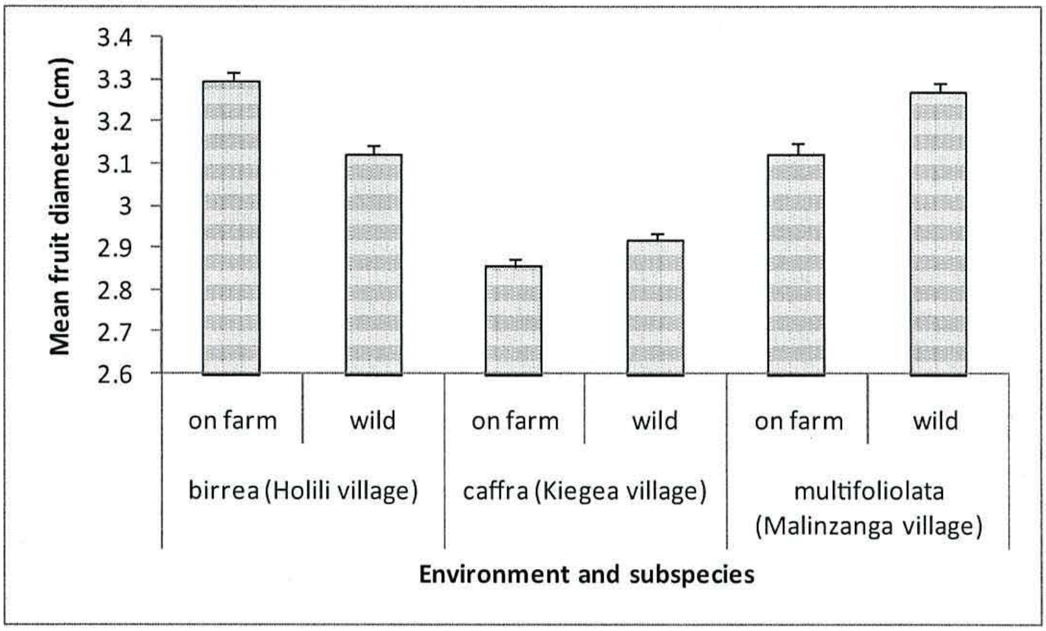

Figure 5. 5: Mean fruit diameter and standard error (cm) of *Sclerocarya birrea* by subspecies and environment

5.3.3 Fruit yield

5.3.3.1 All the subspecies

In general it was found that there were more fruits and weight (kg) per tree in the wild than on farm population (Table 5.2). The table also shows that number and weight of fruits was less in 2009 (when there was less rainfall – figure 5.1) than in 2008. Mean and range of fruits per tree produced in the wild was 5924 ± 742 fruits/tree; range = 673 – 13046 fruits/trees; while mean and range of fruits/trees for on farm trees was 4395 ± 609 fruits/tree; range = 528 - 11891 fruits/tree for year 2008. In year 2009 mean and range of fruits/tree was 3660 ± 503 fruits/tree; range = 424 - 9384 fruits/tree for trees in the wild and 2733 ± 402 fruits/tree; range = 229 – 8435 fruits/tree for trees on farms.

Mean and range of fruit weight produced by individual trees in the 2008 season was 163.48 ± 22.02 kg; range = 16.15 - 392.79kg and 116.46 ± 16.73 kg; range = 13.74 - 330.22 kg for wild and on farm populations respectively. For the 2009 season the mean and range of weight was 100.72 ± 14.88; range = 10.17 - 282.54 kg and 72.14 ± 10.87 kg; range = 5.50 - 219.55kg for wild and on farm populations respectively.

Using analysis of variance (one way ANOVA) we found a significant difference ($p < 0.01$) in fruit yield per tree between the subspecies ($F = 10.68$; $\alpha = 0.001$; $DF = 2$) with subspecies *multifoliolata* and *caffra* having the highest and least number and weight of fruits per tree respectively. Independent t test (two tailed) showed that the only significant difference between the means was in terms of fruit weight in year 2008 ($p < 0.1$; $t = -1.70$) where wild populations had more fruit weight/tree than on farm population. However t-test (paired) showed that number and weight of fruits per tree for year 2008 were significantly higher ($p < 0.001$) than the 2009 yield.

Table 5. 2: Mean, standard error and range of fruit counts and weight per tree for a combined data for all subspecies of *Sclerocarya birrea*

Variable	Environ ment	Mean + SE by year		Range by year	
		2007/08	2008/09	2007/08	2008/09
Fruits per tree (counts)	On farm	4395 ± 609	2733 ± 402	528 - 11891	229 - 8435
	Wild	5924 ± 742	3660 ± 503	673 - 13046	424 - 9384
Fruit weight per tree (kg)	On farm	116.46 ± 16.73	72.14 ± 10.87	13.74 - 330.22	5.50 - 219.55
	Wild	163.48 ± 22.02	100.72 ± 14.88	16.15 - 392.79	10.17 - 282.54

5.3.3.2 Yield for subspecies *caffra*

For subspecies *caffra* the number and weight of fruits per tree for wild population was higher than that for on farm population and number of fruits and weight per tree was more in 2008 than in 2009 as shown in figure 5.6 and 5.7. The mean and range of number of fruits per tree for the 2008 season was 2173 ± 357 fruits/tree (range = 724 - 3958 fruits/tree) and 3021 ± 814 fruits/tree (range = 673 - 8391 fruits/tree) for the on farm and wild populations respectively. For the 2009 season fruit production declined to 1309 ± 199 fruits/tree (range = 229 - 2254 fruits/tree) and 2029 ± 519 fruits/tree (range = 424 - 5130 fruits/tree) for the on farm and wild populations respectively.

Mean and range of weight of fruits in 2008 season was 52.21 ± 8.57 kg/tree (range = 17.40 - 95.10 kg/tree) and 72.49 ± 19.54 kg/tree (range = 16.15 - 201.36 kg/tree) for on farm and wild populations respectively. For 2009 season the mean weight was 31.46 ± 4.78 kg/tree (range = 5.50 - 54.16 kg/tree) and 48.68 ± 12.46 kg/tree (range = 10.17 - 123.11 kg/tree) for on farm and wild populations respectively.Using independent t-test it was found that the differences in number and weight of fruits per tree was not significant between the environments but paired t-test showed that number and weight of fruits per tree was significantly different between the years ($p < 0.001$)

5.3.3.3 Yield for subspecies *multifoliolata*

Fruit production in terms of number and weight per tree for subspecies *multifoliolata* is also presented in figure 5.6 and 5.7. In the 2008 season mean number of fruit produced was 6026 ± 1119 fruits/tree (range = 1296 - 11891 fruits/tree) and 9192 ± 1030 fruits/tree (range = 4237 - 13046 fruits/tree) for on farm and wild populations respectively. In the 2009 season there were 3226 ± 693 fruits/tree (range = 815 - 5608 fruits/tree) and 5551 ± 915 fruits/tree (range = 1346 - 9384 fruits/tree) in on farm and wild populations respectively.

Fruit weight was 167.36 ± 31.08 kg/tree (range = 35.99 - 330.22 kg/tree) and 276.75 ± 31.00 kg/tree (range 127.57 - 392.79 kg/tree) for on farm and wild populations respectively in the 2008 season while in the 2009 season fruit weight was 89.58 ± 19.25 kg/tree (range = 22.63 - 155.74 kg/tree) and 167.14 ± 27.54 kg/tree (range = 40.53 - 282.54 kg/tree) for on farm and wild populations respectively.Therefore the mean number and weight of fruits per tree for subspecies *multifoliolata* was high for wild populations than on farm populations and was also high for the 2008 season than the 2009 season. Independent t -test showed a significant difference in the means for yield and weight of fruits per tree between the two environments ($p< 0.1$ for yield and $p < 0.05$ for weight). Paired t-test showed a significant difference ($p < 0.001$) in the means for yield and weight of fruits per tree between 2008 and 2008.

5.3.3.4 Yield for subspecies *birrea*

Fruit production in terms of number and weight per tree for subspecies *birrea* is presented in figure 5.6 and 5.7; showing more fruits and weight from the wild than on farm populations and season 2008 than season 2009. In the 2008 season mean number of fruit production was 4987 ± 1152 fruits/tree (range = 528 - 10218 fruits/tree) and 5562 ± 1210 fruits/tree (range = 815 - 11619 fruits/tree) for on farm and wild populations respectively. In the 2009 season there were 3401 ± 799 fruits/tree (range = 741 - 8968 fruits/tree) and 3664 ± 834 fruits/tree (range = 492 - 8435 fruits/tree) in on farm and wild populations respectively.

Fruit weight was 129.80 ± 29.97 kg/tree (range = 13.74 - 265.96 kg/tree) and 141.22 ± 30.73 kg/tree (range 20.69 - 295.03 kg/tree) for on farm and wild populations respectively in the 2008 season while in the 2009 season fruit weight was 95.38 ± 21.70 kg/tree (range = 12.81 - 219.55 kg/tree) and 86.34 ± 20.29 kg/tree (range = 18.82 – 227.71 kg/tree) for on farm and wild populations respectively. Using independent t test it was found that the mean values for yield and weight per tree for subspecies *birrea* were not significantly different between the two environments. But paired t-test showed a significant difference ($p < 0.01$) in mean values of yield and weight per tree between 2008 and 2009 seasons.

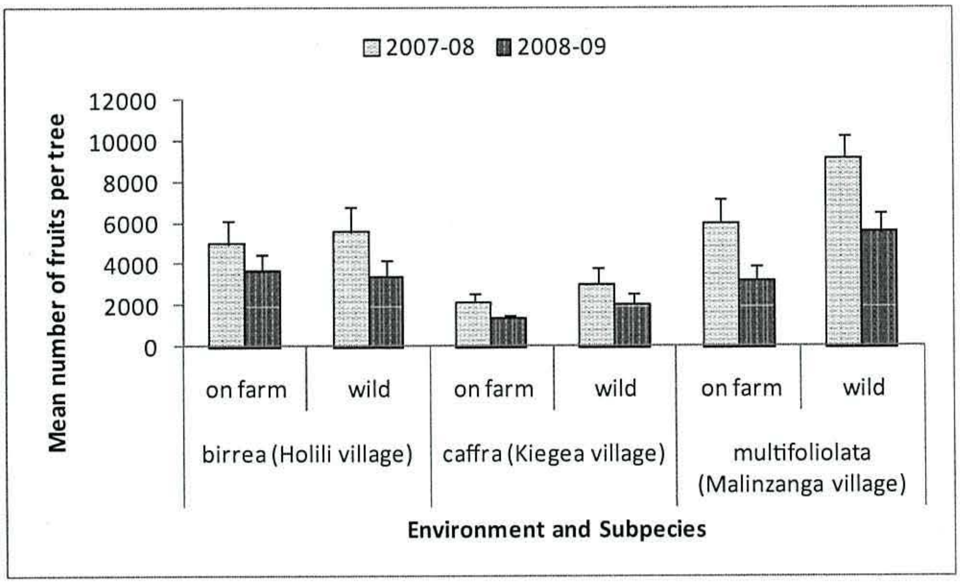

Figure 5. 6: Mean and standard error of number of fruits per tree for *Sclerocarya birrea* by subspecies, environment and year

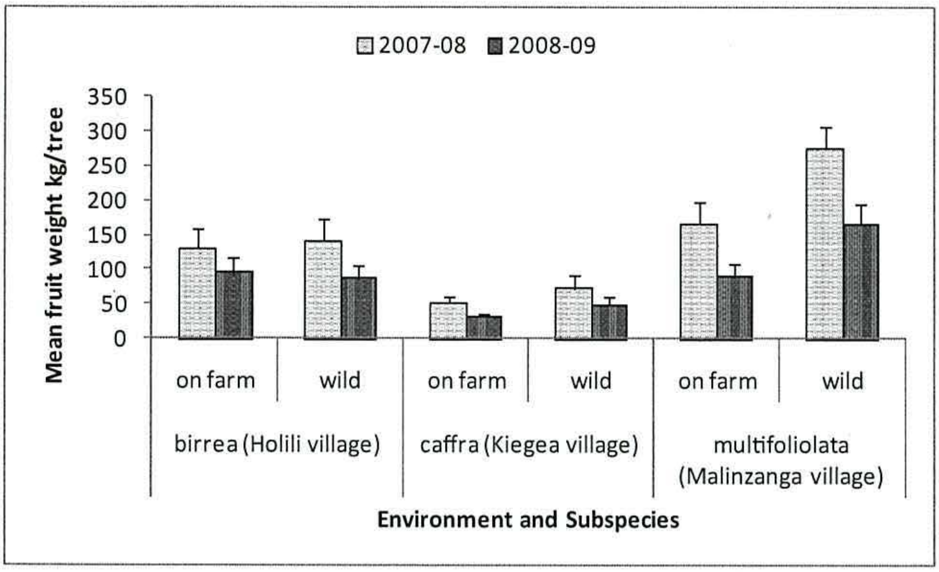

Figure 5. 7: Mean and standard error of weight of fruits per tree for *Sclerocarya birrea* by subspecies, environment and year

5.3.4 Relationship between fruit yield and tree dendrometric variables

Fruit yield was related to crown diameter, tree height and diameter at breast height (DBH) and results are shown in figure 5.8. Crown diameter showed the strongest positive relationship with number of fruits produced; $R^2 = 0.72$ for the 2008 season, and $R^2 = 0.62$ for the 2009 season. Tree height and DBH also showed positive relationship with fruit yield per tree although this was weak. Regression analysis gave the following relationship between fruit yield and the various fruit parameters:

$$Y = 33x + 737w - 14.8z - 2211$$

Where; Y = Fruit yield; x = tree height; w = crown diameter; z = tree DBH

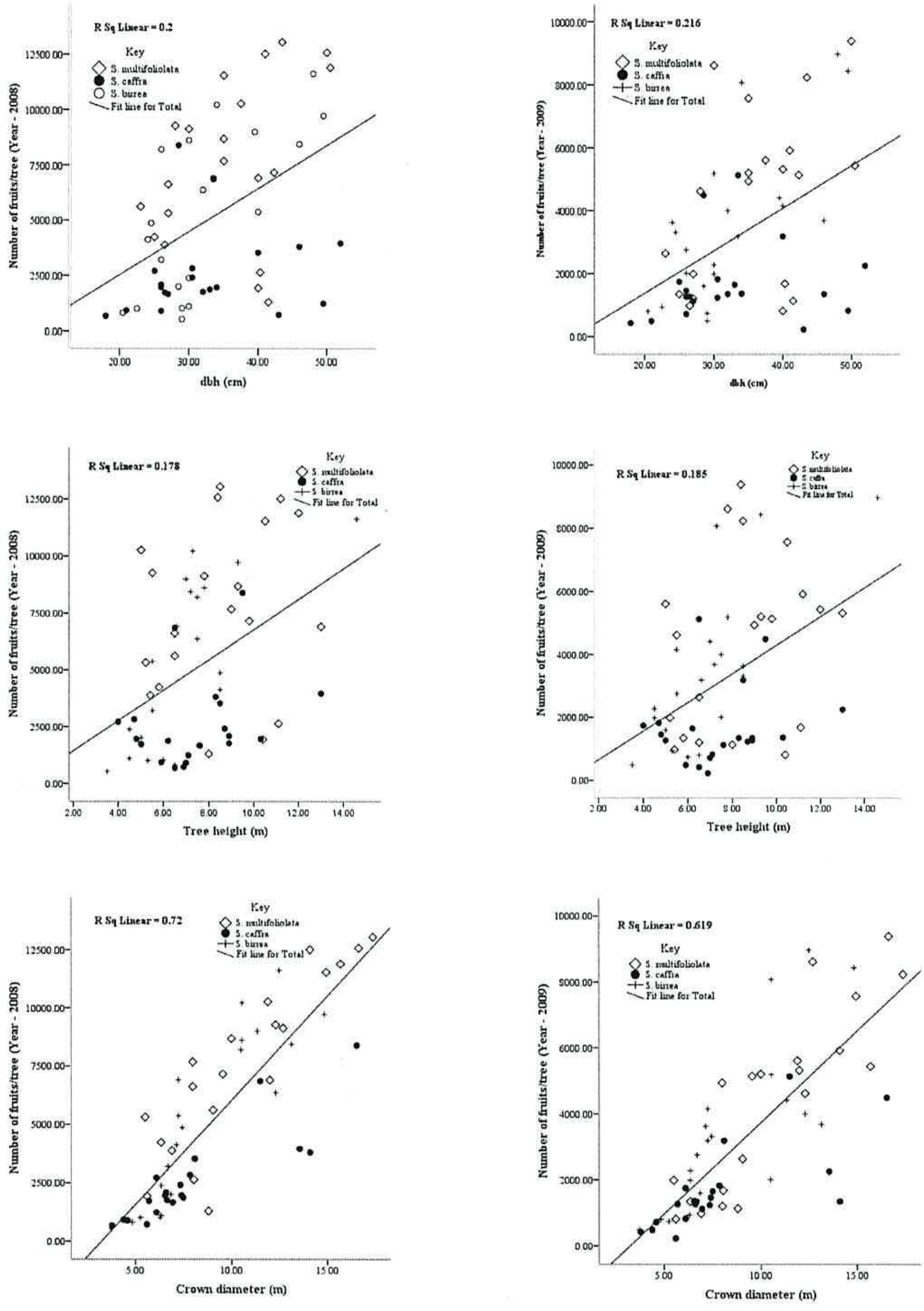

Figure 5. 8: Relationship between number of fruits per tree with crown diameter, height and DBH of *Sclerocarya birrea* trees

5.3.5 Phenology

5.3.5.1 Leafing

i) Leafing of female trees for subspecies *multifoliolata* in on-farm environment

Six different leafing events for subspecies *multifoliolata* are shown in Figure 5.9for duration of two years. In January 2008 there were no trees in bud breaking stage implying that the process had already taken place in the end of 2007. Leaf flushing was observed in 60% of the trees with 20% of them carrying on with the process into February. However all the trees had new leaves in January and by mid February the leafing process ended. Another leafing activity which was observed in January was 70% of the trees having mature leaves. By February all of them had reached the peak of mature leaves and they remained so up to June. Shedding started in May with 10% of the trees. The shedding activity was at the peak in June and lasted in July where all leaf phenological activities came to a rest.

Another cycle of leafing events started with bud break in October 2008 and was observed in 30% of the trees. Bud break was at the peak (80% of the trees) in November and lasted in December where 60% of the plants were still having buds at the breaking stage. By the end of November 70% of the trees were flushing and in December all the trees had reached flushing stage.

In January 2009, 40% of the trees remained flushing but the process did not continue to the end of the month. It should be noted here that in the previous year; where there was more rainfall, flushing continued to February. Development of new leaves had started in November 2008 with 40% of the trees and by January 100% of the trees were having majority of new leaves, then declining to 40% and 30% in February and mid March respectively. It can be seen that in 2009, the new leaf stage was prolonged when compared to the previous year probably due to the less rainfalls received. There were few (in 20% of the trees) mature leaves in December, increasing to 80% in January and peaking (100% of the trees) in February. All trees remained leafy until June and by mid July they become leafless. Shedding was in 50%, 80% and 20% of the trees in May, June and July respectively.

The trees remained leafless until the last weeks of November 2009 where 60% of the trees were flashing and 20% had developed new leaves. Another bud breaking started with 30% of trees in October, peaking to 100% of the trees in November and 20% of the trees finishing bud breaking in December. Also in December 100% of the trees were flushing and 80% had new leaves compared to 70% in the previous year. Overall, there was a variation in the onset and duration of the leafing events, especially flushing, new leafing and shedding, between 2008 and 2009 but in both years the trees became leafless in July, at the peak of cold/dry season.

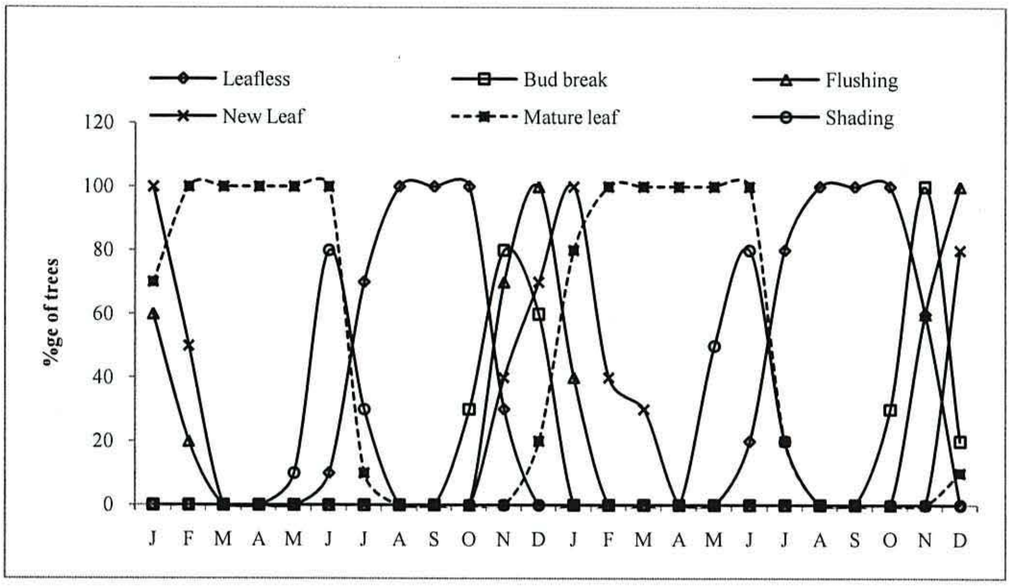

Figure 5. 9: Leafing phenophases for on farm female trees subsp. *multifoliolata* (Jan 2008 - Dec 2009)

ii) Leafing of male trees for subspecies *multifoliolata* in on-farm environment

For male trees, some of the leafing process were starting late by generally few weeks up to a month compared to females (Figure 5.10). In January 2008 the trees were 20%, 50%, 70%, 60%, 40% at bud break, leaf flush, new leaf and mature leaf stages respectively. Flushing ended in February by 30% of the trees but 80% of the trees had new leaves up to the 3rd week of March. Note that for females new leaves were last observed in February. Leaf maturity stage started in January by 40% of the trees, peaking to 100% in February and remaining so up to end of May. By June 70% of the male tree had leaves as shedding started in May with 80% of the trees shedding leaves in June and 20% of them already leafless. 20% of trees finished shedding early July and therefore all the trees become leafless in this month until mid December.

From mid to end of November 2008, 40% were at bud breaking process continuing with 80% in December and lasting end of January, 2009 with 20% of the trees. Leaf flushing started in December by 70% of the trees with peak flushing in January and end of flushing in February with 20% of the trees. Few trees (20%) had new leaves in December but there were many, 70% and 60%, in January and February respectively. By the end of January 30% of the leaves were at the maturity stage and all the trees reached this stage at the end of February. All trees had mature leaves up until June with about 40% with leaves in July, although by the end of the month all of them had become leafless. Shedding started in early June and lasted in July. Trees remained leafless until the third week of December when they started leafing again. By the end of year 80% were still leafless while 80%, 60% and 20% were at bud breaking, flushing and new leaf stages respectively.

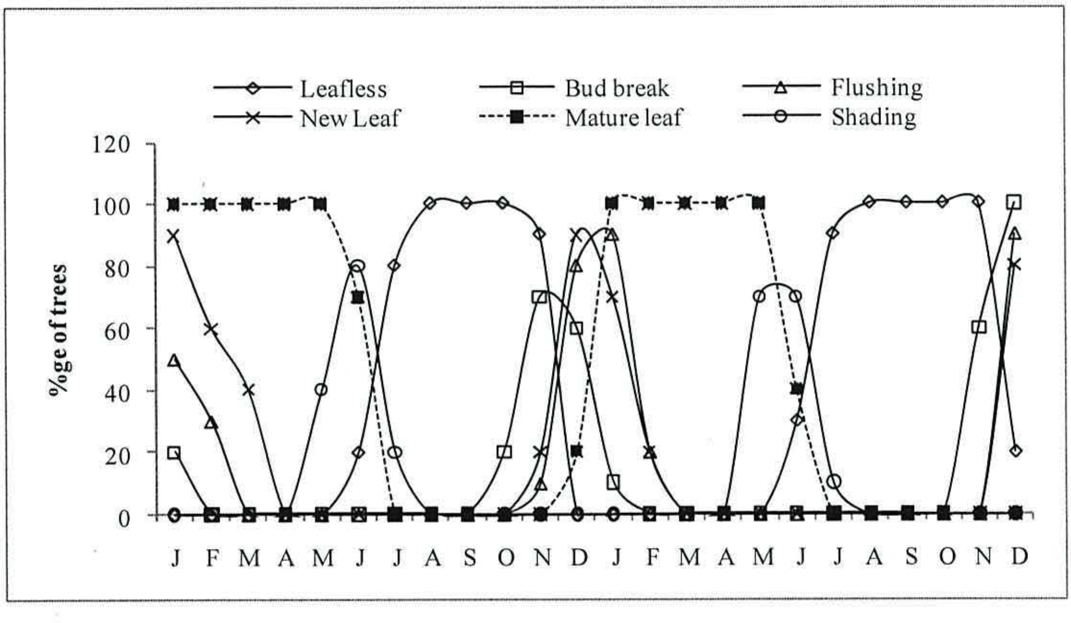

Figure 5. 10: Leafing phenophases for on farm male trees subsp. *multifoliolata* (Jan 2008 - Dec 2009)

iii) Leafing of female trees for subspecies *multifoliolata* in wild environment

Figure 1.11 shows phenophases presented in this section. For the wild population in January 2008, there were 30% of trees still at the bud breaking stage contrary to the on-farm population which had finished this stage. Therefore for subsp. *multifoliolata* another variation on phenophases, in addition to sex of trees and response to rainfall, was between the environments which the populations were assessed. Unlike the on farm population, in January there were no trees with mature leaves and 60% of the trees were flushing and had new leaves. Flushing continued into February with 30% of the trees while all trees had new leaves at this stage. The first mature leaves started to appear in February with 40% of the trees while for on farm population, mature leaves were observed on 70% of the trees in January. All trees had mature leaves in March with 40% of them still bearing new leaves in the first weeks. Mature leaves lasted for a shorter time than the on farm plants; by end of May, 20% of the trees were leafless and 60% were shedding leaves. All trees become leafless in June.

All the trees remained leafless up to November with 50% and 20% of them still leafless in December and January, 2009 respectively. Bud breaking started in November with 80% of the trees and going through to December and January with 60% and 20% of the trees respectively. Flushing was 70%, 90% and 20% in December, January and February respectively while trees with new leaves were 40%, 100%, 50% and 20% in December, January, February and March respectively. All trees had mature leaves in March after starting with 70% of the trees in February. All the trees continue to have mature leaves until May with 60% of them breaking into June where 40% had become leafless in May. Unlike on farm trees, shedding for wild female trees were rapid where 80% and 60% of trees were shedding in May and June respectively; by the end of June, shedding ended and all trees were leafless. All trees remained leafless until November and 70% were still leafless in December. Bud breaking was on 70% and 100% of trees in November and December and there were 70% trees flushing and 30% of trees with new leaves in December.

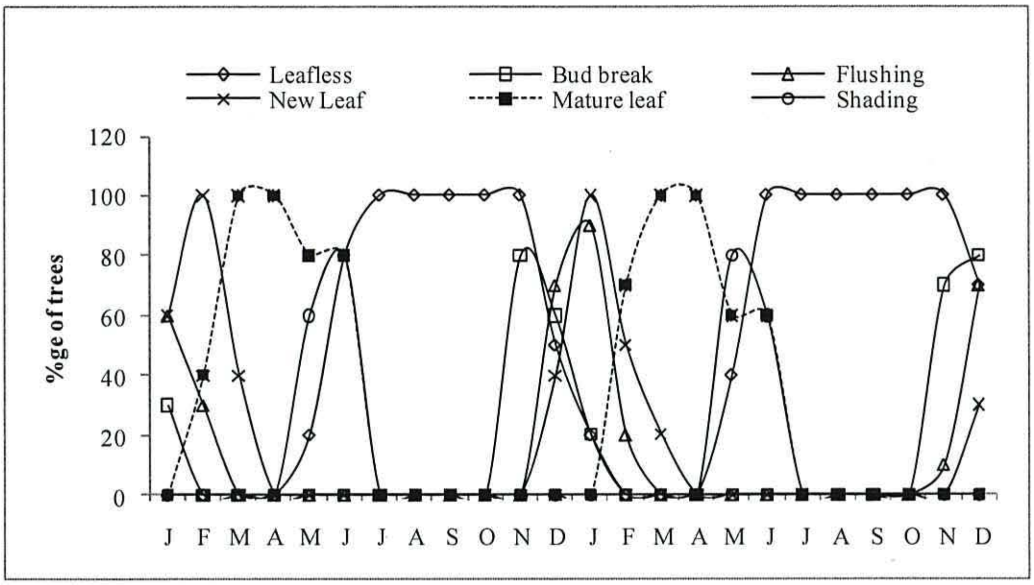

Figure 5. 11: Leafing phenophases for wild female trees subsp. *multifoliolata* (Jan 2008 - Dec 2009)

iv) Leafing of male trees for subspecies *multifoliolata* in wild environment

Figure 5.12 presents phenophases for this section. The figure shows that as it was for on farm population, males developed leaves late and had a relatively shorter leafy stage than females. Up to 60% of the male trees were at the stage of bud breaking compared to only 30% of the female trees in January 2008. Flushing increased from 30% in January to 80% in February, the process ending in March with 30% of the trees. Trees with new leaves in January were 30%, peaking at 100% in February and declining to 80% in March and ending at 20% in April. Leaves begin to attain maturity in February with 30% of the trees and by March all of the trees had mature leaves remaining at that stage until May. Shedding started in May with 30% of the trees becoming leafless in the same month and all trees were leafless by the end of June.

The trees maintained the leafless status until December 2009 where only 10% had started to bear new leaves. By the end on November 40% of the trees were at bud break with 80% being observed in December and 40% in January. Flushing was 30%, 80%, 60% and 30% in December, January, February and March respectively. New leaves were observed in 10%, 90%, 60% and 20% in December, January, February and March respectively. A few trees had mature leaves in February but all trees had mature leaves from March through to May. Shedding started in May in 50% of the trees and 10%

become leafless. Shedding continued and ended in June with the remaining 90% of the trees. All trees remained leafless for the rest of the year with the exception of 20% which developed new leaves towards the end of December. So in December 80% of the trees were still leafless while 80%, 30% and 20% of the trees were at the stage of bud breaking, leaf flush and new leaf respectively.

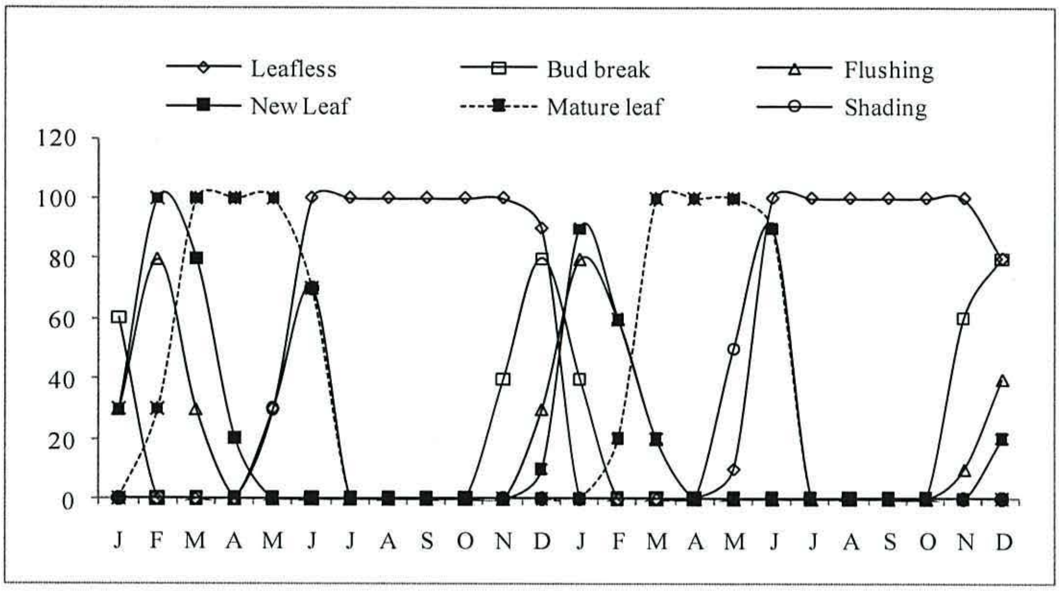

Figure 5. 12: Leafing phenophases for wild male trees subsp. *multifoliolata* (Jan 2008 - Dec 2009)

v) Leafing of female trees for subspecies *caffra* in on-farm environment

In January and February 2008, 50% of the trees were in bud breaking process, ending in March with 10% of the trees. In the same month of January there were 60% and 30% of trees at the stage of flushing and new leaves respectively. Trees continued to flush in February (50%), March (40%) and April (10%) and developing new leaves in February (60%), March (80%), April (40%) and May (20%). Mature leaves were observed in February in 60% of the trees and March (70%), April, May & June (100%), July (70%) and August (30%). Shedding started in May, was highest in July (70%) and ended in August.

Trees remained leafless until January 2009 when 20% of the trees had developed new leaves. The leafing processes in this season were as follows: bud breaking in November (10%), December (30%), January (70%), February (40%) and March (20%); flushing in December (10%), January (50%), February (80%), March (30%) and April (10%);

development of new leaf in January (20%), February (70%), March (70%), April (50%) and May (30%); leaf maturity in February (60%), March (80%), April (100%), May (100%), June (100%), July (80%) and August (20%); and leaf shedding in June (50%), July (80%) and August (20%).

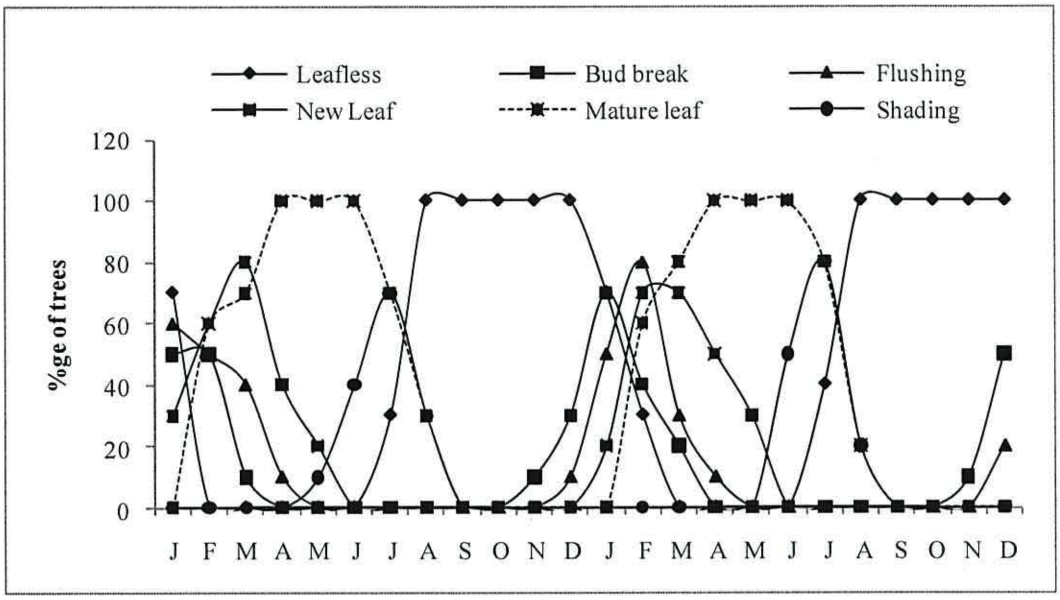

Figure 5. 13: Leafing phenophases for on farm female trees subsp. *caffra* (Jan 2008 - Dec 2009)

Trees remained leafless for the rest of the year although in November and December bud breaking and flushing processes had started. So unlike subspecies *multifoliolata*, for subspecies *caffra* leafing phenophases tended to begin late and continued to be observed until August.

vi) Leafing of male trees for subspecies *caffra* in on-farm environment

For the male plants, 100% and 70% were leafless in January and February respectively. Bud breaking was in January (80%), February (60%) and March (20%) while flushing was from January (20%) to May (10%). New leaves were developing from February (30%) to May (10%) while mature leaves started to appear in February (20%) peaking in April (100%) and lasting in August (60%). When compared with the females, the male plant leaves were developing late and slowly e.g. note the percentage of plants in bud breaking in January and those with leaves in August for females and males.

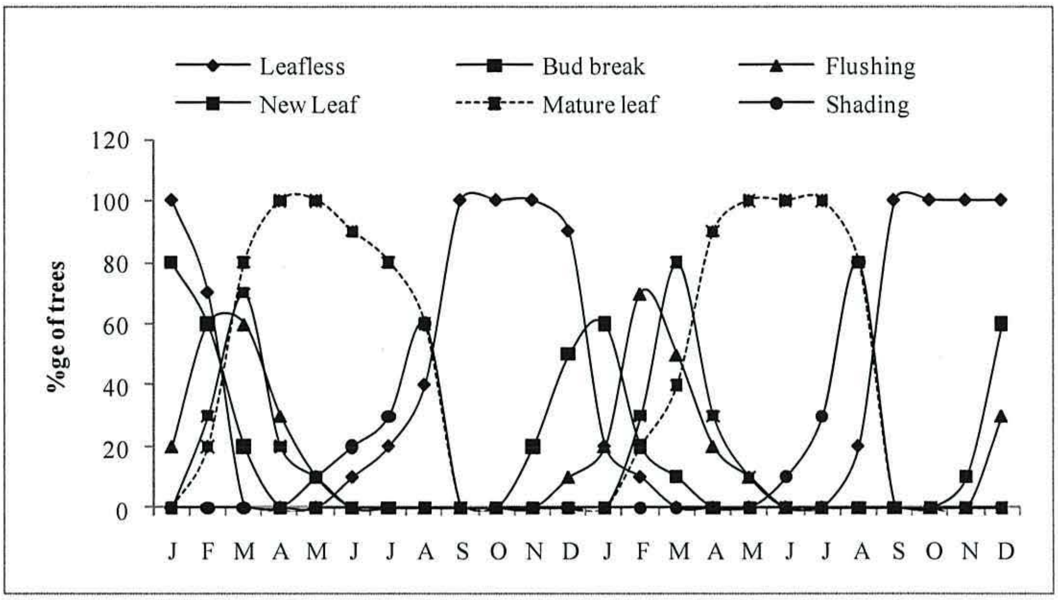

Figure 5. 14: Leafing phenophases for on farm male trees subsp. *caffra* (Jan 2008 - Dec 2009)

The following season the leafing processes followed the same trend i.e. bud breaking in November (20%), December (50%), January (60%), February (20%), March (10%); Flushing in December (10%), January (20%), February (70%) and March (50%), April 20% and May (10%); New leaves in February (30%), March (80%) and April (30%) and May (10%); Leaf maturity in February (20%), March (40%), April (90%), May-July (100%) and August (80%). Shedding started in May with 10% and lasted in August with 80% and the trees remained leafless for the rest of the year.

vii) Leafing of female trees for subspecies *caffra* in wild environment

Leafing appeared to start later in the wild than on farms because in January 2008, there were 100% leafless trees and 60% of trees in bud breaking stage in the wild. Bud breaking. continued in February (60%) and March (30%) while flushing was taking place in January (20%), February (60%), March (70%), April (50%) and (May 30%). New leaves started to emerge in February (10%) and continued through to March (40%), April (80%) and May (60%). Leaf maturity was first attained in March (20%) peaking in April to June, dropping in July (80%) and all becoming leafless in August.

All trees remained leafless for the rest of the year but started bud breaking (50%) in December and flushing (20%) in January 2009; both processes continuing until March. New leaves started in February with 10% of the trees, increased to 40% in March and the last (60%) new leaves were observed in May. Leaf maturity started in March with 20% of the plants, increased to 80% in April, 100% in May and June, and dropping to 90% and 70% in July and August respectively. Shedding had started slowly in June and peak shedding was in end of July and beginning of August.

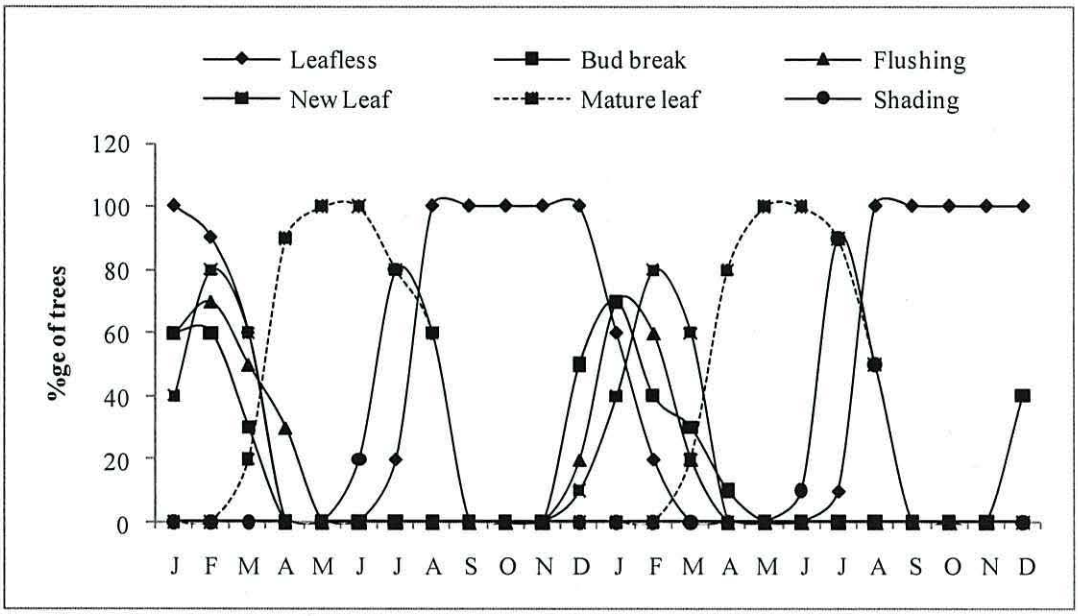

Figure 5. 15: Leafing phenophases for wild female trees subsp. *caffra* (Jan 2008 - Dec 2009)

viii) Leafing of male trees for subspecies *caffra* in wild environment

For male plants all trees were leafless in January 2008 and still 30% were leafless by February. Bud breaking and flushing was observed in all trees in January and the two processes lasted in March (20%) and April (10%) respectively. New leaves started in February with 10%, increased to 80% in March, before declining to 40% and 30% in April and May respectively. Leaf maturity started to appear in March in 40% of the trees, increased to 70% in April, peaking to 100% in May and June before dropping to 90% and 60% in July and August respectively. Shedding started in June (10%), peaked in July (100%) and lasted in August (60%).

Trees continued to be leafless until January 2009 with bud breaking taking place in 20% of the trees in December and 30% flushing in February. All the trees were at bud breaking in January, 40% in February and ended in March with 20% of the trees. Flushing was at the peak in March (80%) and dropped to 40% and 20% in April and May respectively. There were new leaves in March (80%), April (40%) and May (20%)

and mature leaves in March (30%), April (60%, May-June (100%), July (90%) and August (10%). Shedding started in June (10%), peaked in July (100%) and ended in August (20%). The trees remained leafless for the rest of the year and in December 30% of the trees were in the stage of bud breaking. Male trees phenophases were lagging a little bit behind than female trees phenophases

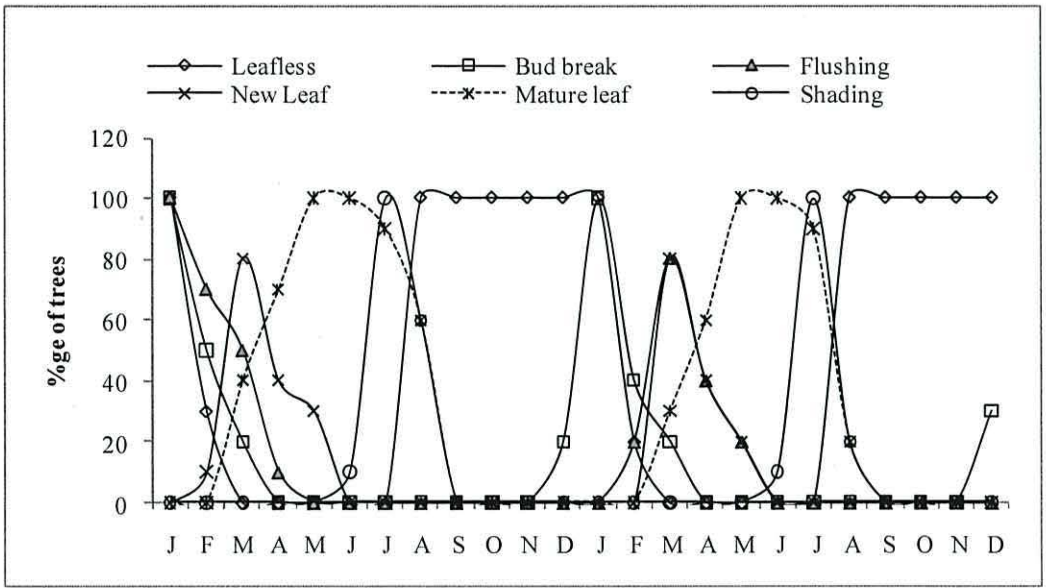

Figure 5. 16: Leafing phenophases for wild female trees subsp. *caffra* (Jan 2008 - Dec 2009)

ix) Leafing of female trees for subspecies *birrea* in on-farm environment

Of the three subspecies, all phenological events were earliest in subspecies *birrea*. In January 2008 there were no trees at bud break or flushing, 80% were having new leaves and 100% had mature leaves. There were still some few (20%) trees with new leaves in February but all of them had mature leaves and maintained the status until May. Shedding which was quick started in May with 40% of the trees and ended in June with 80% of the trees.

Trees remained leafless until October when new leaves started to develop. Bud breaking, flushing and new leaves all started in October with 40%, 20% and 10% of the trees respectively. In November 80%, 90% and 30% of the trees were observed to be in bud breaking, flushing and new leaves respectively while in December 20% were in bud breaking and flushing while 60% had new leaves and 40% had mature leaves. New leaves were observed for the last time in January in 80% of the trees and mature leaves were also in 80% of the trees. In February all trees had mature trees and remained so until May when shedding started in 30% of the trees. Shedding continued and ended in June with 90% of the trees. The next leafing process started later in October and followed the same trend.

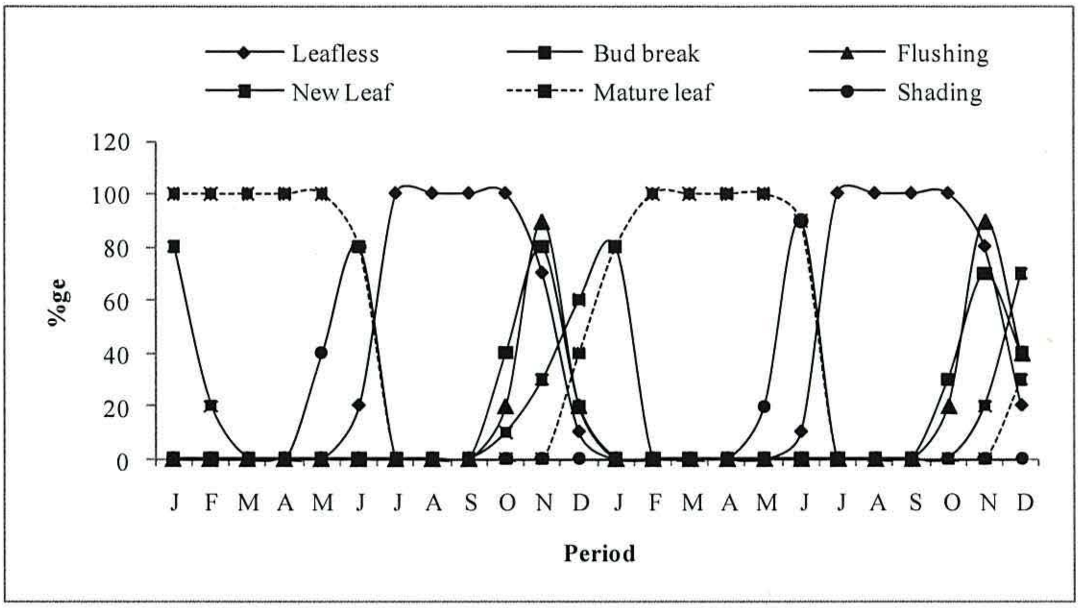

Figure 5. 17: Leafing phenophases for on farm female trees subsp. *birrea* (Jan 2008 - Dec 2009)

(x) Leafing of male trees for subspecies *birrea* in on-farm environment

Contrary to females, in January 2008, 20% of male trees were still flushing while there were 70% of the trees with new leaves in February. There were also 70% of trees with mature leaves in January and it was until February when all of them had mature leaves, maintaining the status until June. All shedding took place in June for all trees. Trees were leafless until November where 60% were flushing and 20% had new leaves. Bud breaking had started in October with 10% of the trees, peaked in November where all trees were at bud break then dropping in December to 40%. In December 100% of the trees were flushing and 90% had new leaves while in January 60%, 70% and 60% were at the stage of flushing, new leaves and mature leaves respectively. In February there were 60% of trees with new leaves and 100% with mature leaves with the later stage being maintained until June. As it was for the previous season, shedding started and ended in June for all trees. The trees remained leafless until November with a similar trend as the previous season this time with 10% of the trees starting bud break in

October and by the end of December 80% had new leaves with none observed having mature leaves.

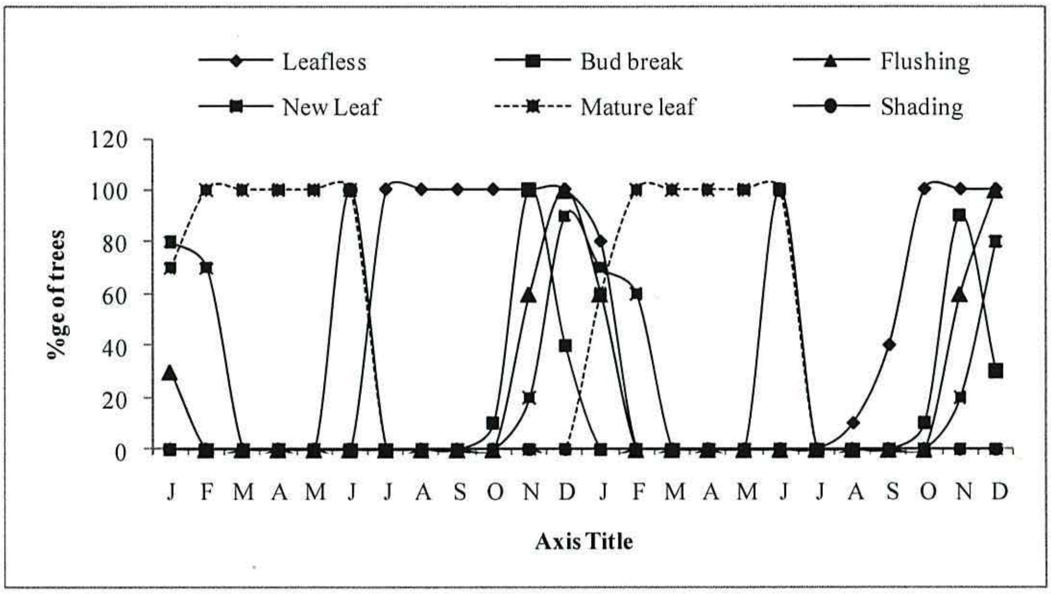

Figure 5. 18: Leafing phenophases for on farm male trees subsp. *birrea* (Jan 2008 - Dec 2009)

(xi) Leafing of female trees for subspecies *birrea* in wild environment

For the wild plants, there were still 10% of the trees observed at the stage of bud break in January 2008 compared to none on the farm population. Flushing, new and mature leaves were observed in 90%, 80% and 60% of the trees respectively in January. In February 40% of the trees were still flushing and all had mature leaves where the later state was observed for all trees until June. Same as on farm, all shedding begin and lasted in June for all trees.

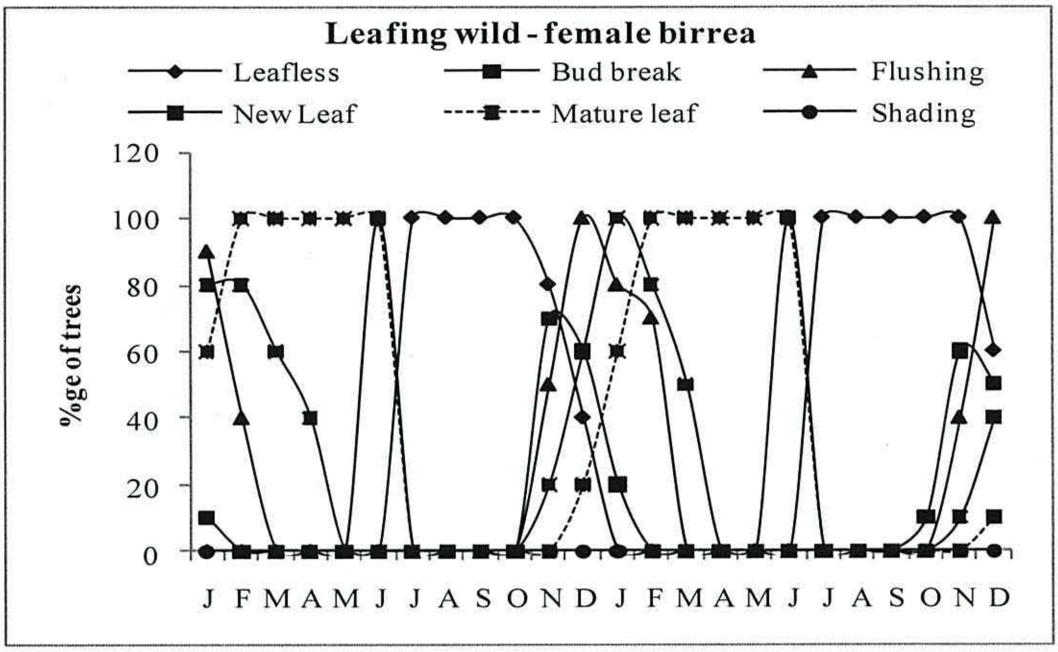

Figure 5. 19: Leafing phenophases for wild female trees subsp. *birrea* (Jan 2008 - Dec 2009)

All trees remained leafless until November when new leaves started to appear on 20% of the trees, with 70% and 50% of the trees at bud break and flushing stage in the same month. In December 40% of the trees were still leafless while 60%, 100%, 60% and 20% were in the state of bud break, flushing, new leaves and mature leaves respectively. In January 2009, bud break, leaf flush, new and mature leaves were observed in 20%, 80%, 100% and 60% of the trees respectively. Flashing ended in February in 70% of the trees and new leaves continued in 80% of the trees in February and ended in 50% of the trees in March. Also by February all trees had mature leaves and continued in the same state until June when shedding begin and finished in the same month. The following season leafing process started with 10%, 60% and 50% of the trees in bud break in October, November and December respectively. Flushing and new leaves were observed in 40% and 10% in November and 100% and 40% in December respectively.

(xii) Leafing of male trees for subspecies *birrea* in wild environment

The process of leafing for male trees was behind to that in female trees. Bud breaking was observes on 30% and 10% of the trees in January and February 2008 respectively while flushing took place until March in 70% of the trees. There were 60%, 90%, 70% and 30% of trees with new leaves in January, February, March and April respectively compared to females where the last new leaves were observed in 40% of the trees in March. There were no mature leaves in January but in February 60% of the trees had mature leaves. All trees had mature leaves in March to June where shedding took place and all trees become leafless.

The trees remained leafless until December where 30% of the trees had developed new leaves. This season 20%, 60%, 40% and 10% of the trees were at bud break in November, December, January and February respectively. Flushing took place in 40%, 50%, 70% and 60% of the trees in December, January, February and March respectively. Trees were observed having new leaves in December (30%), January (70%), February (80%), March (70%) and April (40%). Sixty percent of the trees had mature leaves in February and between March and June all had mature leaves. All trees shed their leaves in June. The following leafing process started in November with 20% of the trees breaking bud; and in December, bud breaking, flushing and new leaves were observed in 50%, 40% and 30% respectively.

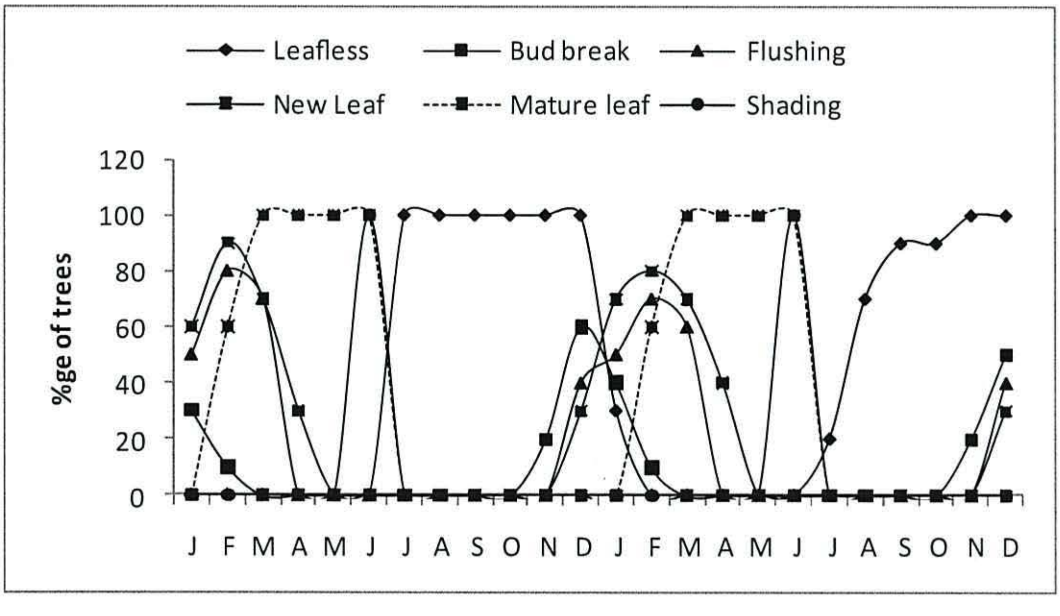

Figure 5. 20: Leafing phenophases for wild male trees subsp. *birrea* (Jan 2008 - Dec 2009)

5.3.5.2 Flowering

i) Flowering of female trees for subspecies *multifoliolata* on-farm environment

Flowering took place along with the initial leafing processes although for males these events were slightly ahead of the leafing process. In January 2008 10%, 20%, 60% and

60% of the flowers were at the stage of bud opening, flower opening, peak flowering, mixed age flowers and drying respectively. The next flowering cycle begun in November with 50% and 10% of the trees in bud break and flower opening stages respectively. The whole process was at the peak in December and January 2009 with most of the bud breaking and flower opening taking place in the beginning of December while peak flowering and mixed age phases started in late December continuing and ending in January.

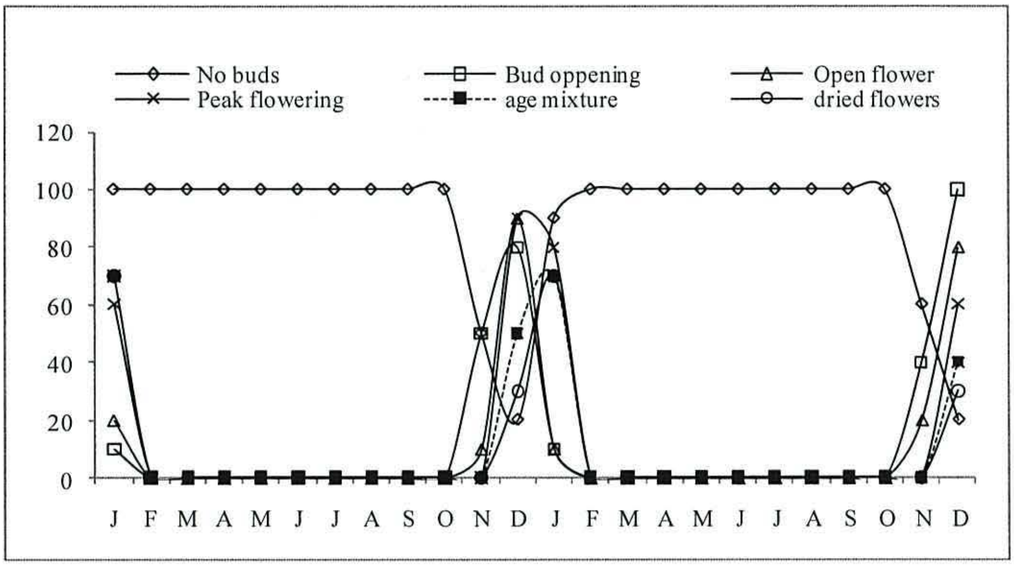

Figure 5. 21: Flowering phenophases for on farm female subspecies *multifoliolata* Jan 2008 - Dec 2009

(ii) Flowering of male trees for subspecies *multifoliolata* on-farm environment

There was 30% of trees which were in the flowering process in January 2008, just beyond the bud breaking stage. The next flowering processes started in October, before females and thereafter followed the same trend as that of female trees flowering but the male flowering was prolonged to February were 30% were at the stage of mixed age and drying off.

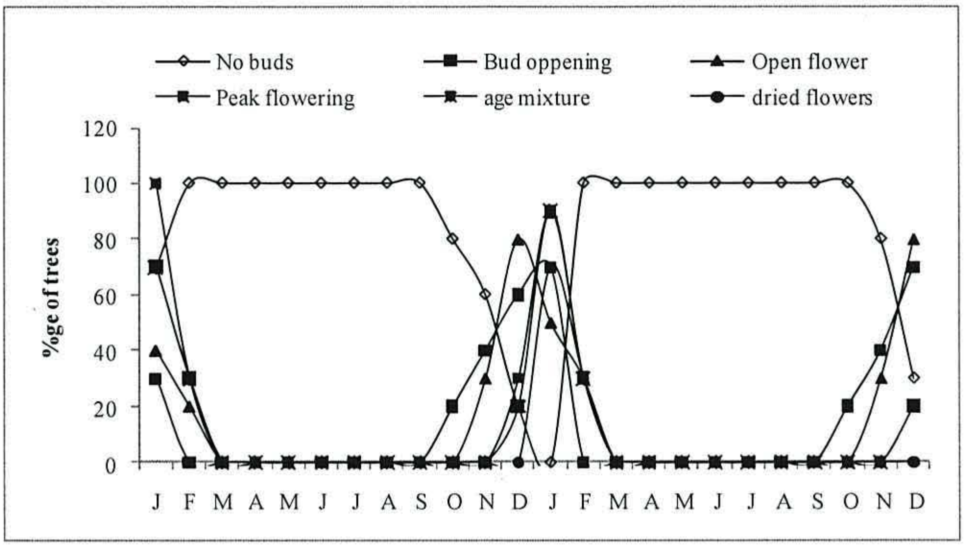

Figure 5. 22: Flowering phenophases for on farm male subspecies *multifoliolata* Jan 2008 - Dec 2009

(iii) Flowering of female trees for subspecies *multifoliolata* in wild environment

In January 2008 there were no flowering plants, only 30% were at the last stage which is drying. Flowering started again in November with 20% at the flowering peak at the end of the month. In December 80% of the trees were at the peak of flowering and the only stage which went through to January 2009 was drying stage by 20% of the trees. The following season had similar trend with 20% and 80% of the trees flowering at the peak in November and December.

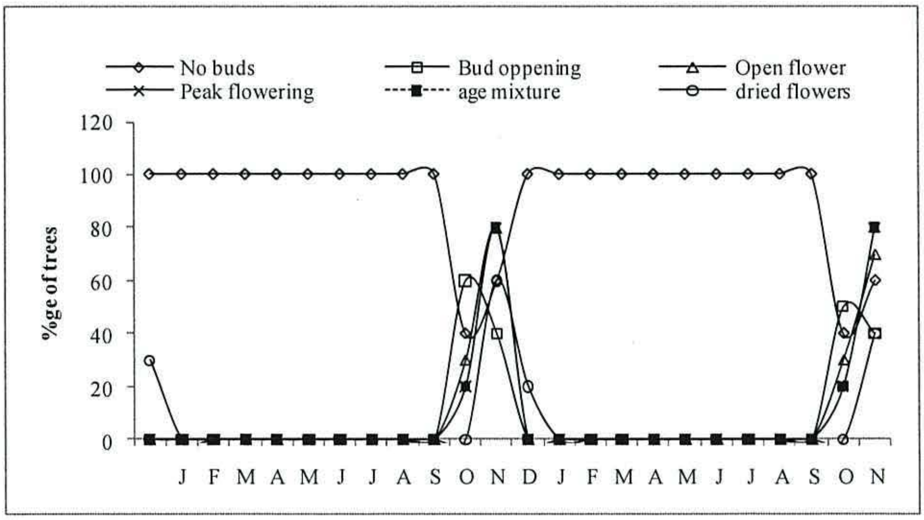

Figure 5. 23: Flowering phenophases for wild female subspecies *multifoliolata* Jan 2008 - Dec 2009

(iv) Flowering of male trees for subspecies *multifoliolata* wild environment

For male trees the flowering events started earlier and end later than those in the female trees. In January 2008 there were 30% of trees at the stage of bud opening while open flowers, peak flowering, age mixture and drying flowers were observed in 40%, 100%, 70% and 70% of the trees respectively. While flowering in females ended in January, the male tree flowers continue to be observed in February with 20%, 30%, 30%, and 30% of trees having flowers at the stages of open flowers, peak flowering, age mixture and drying flowers respectively at the beginning of the month.

The next cycle of flowering started in October with 20% of the trees opening buds. In November 40% and 30% of the trees were opening buds and flowers respectively. The intensity of bud and flower opening increased in December and there were already 30% of trees at the flowering peak. From January the processes followed the trends of the previous year.

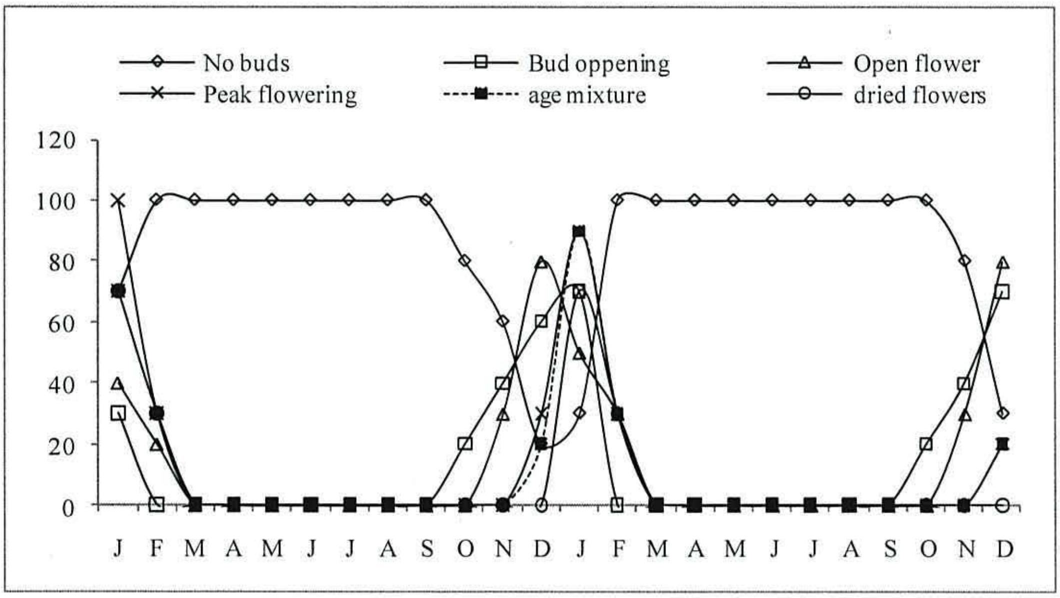

Figure 5. 24: Flowering phenophases for wild male subspecies *multifoliolata* Jan 2008 - Dec 2009

(v) Flowering of female trees for subspecies *caffra* on-farm environment

In January 2008 there were 80% of trees at the peak of flowering and the process ended in Febaruary with 30% of the trees with mixed age and dried flowers. The following season started in November with 30% of trees and peaked in December with 100% of the trees. In January 2009 there were still 50% of the trees in the flowering process and 20% made it into February. Later that year the process started in December.

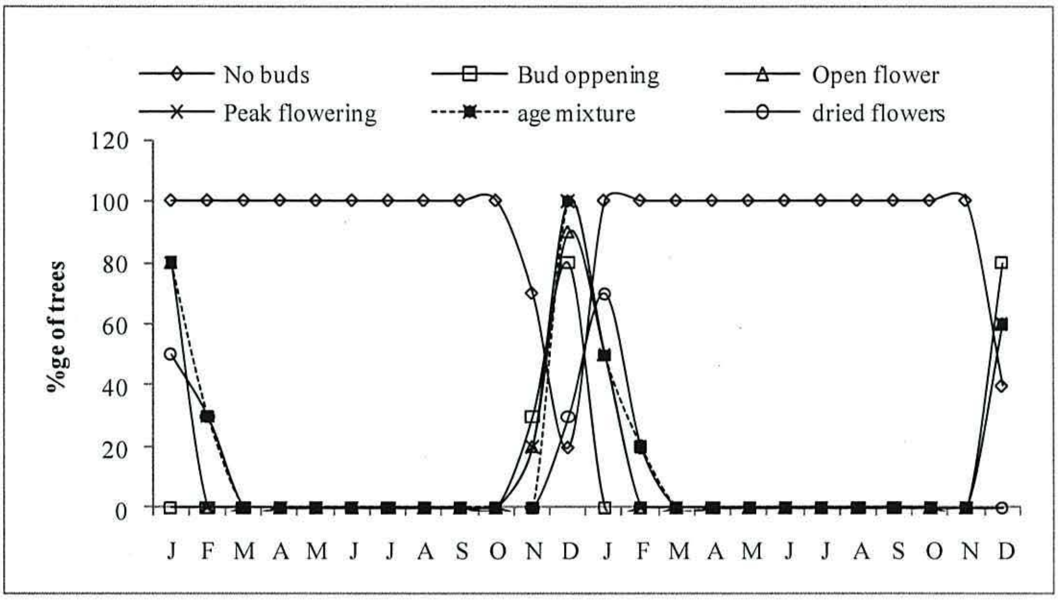

Figure 5. 25: Flowering phenophases for on farm female subspecies *caffra* Jan 2008 - Dec 2009

(vi) Flowering of male trees for subspecies *caffra* on-farm environment

Peak Flowering was observed in January in all trees with 30% of the trees still with opening buds. The process lasted in February with 20% and 60% of the trees at mixed age and drying process respectively. Flowering resumed in November with 60% of the trees, reaching peak flowering in December and January 2009. The process ended in February with 40% of the trees in the state of mixed age flowers and resumed again in November with 50% and 30% of the trees at bud opening and open flower stages respectively.

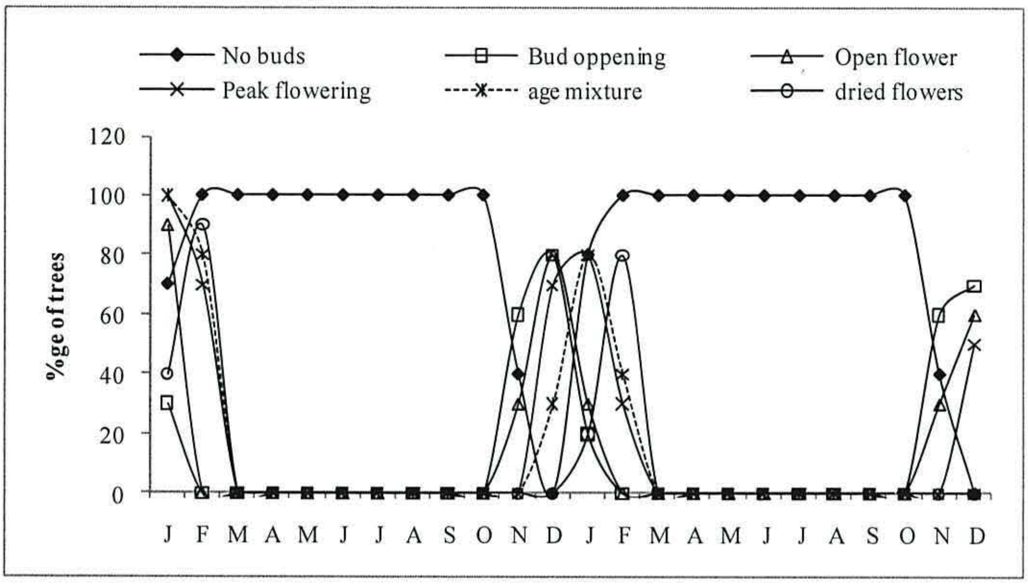

Figure 5. 26: Flowering phenophases for on farm male subspecies *caffra* Jan 2008 - Dec 2009

(vii) Flowering of female trees for subspecies *caffra* in wild environment

There were 60% of trees in flowering process in January 2008. The next process took place from November and into the January 2009, with peak flowering towards the end of December 2008. The trend was similar in the end of 2009 but with 80% trees at the peak of flowering unlike 100% in the preceding season.

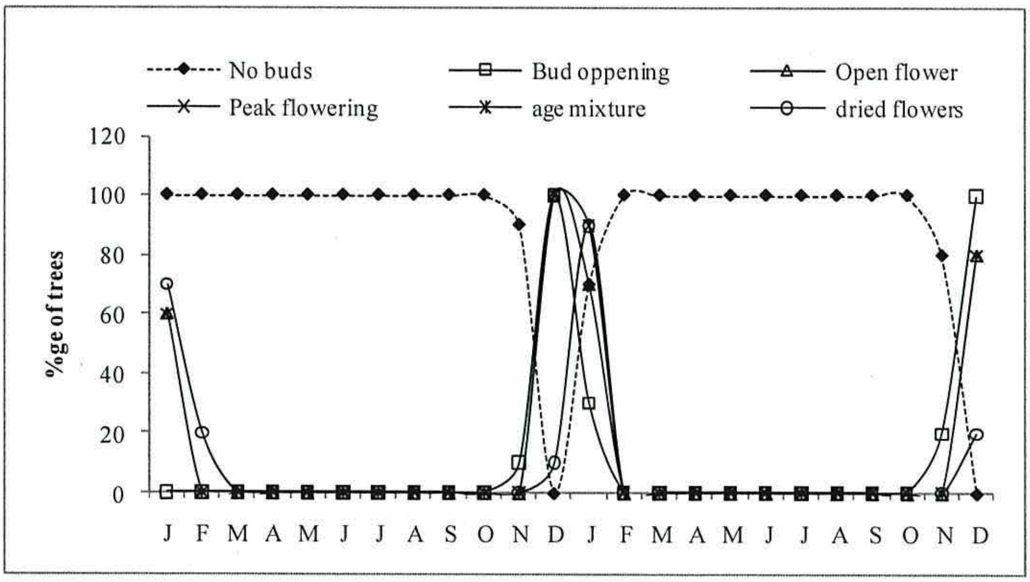

Figure 5. 27: Flowering phenophases for wild female subspecies *caffra* Jan 2008 - Dec 2009

(viii) Flowering of male trees for subspecies *caffra* in wild environment

Flowering for males in January 2008 was observed in many trees compared to females. Trees which were at peak of flowering were 100% in January and 20% in February. The following flowering season started in November where 40% and 20% of the trees were at bud and flower opening respectively. In December 80%, 60%, 40% of trees at bud opening, peak flowering and mixed age stage. In January 2009 there were still many trees at the peak of flowering while in February there were still 30% of the trees at peak flowering.

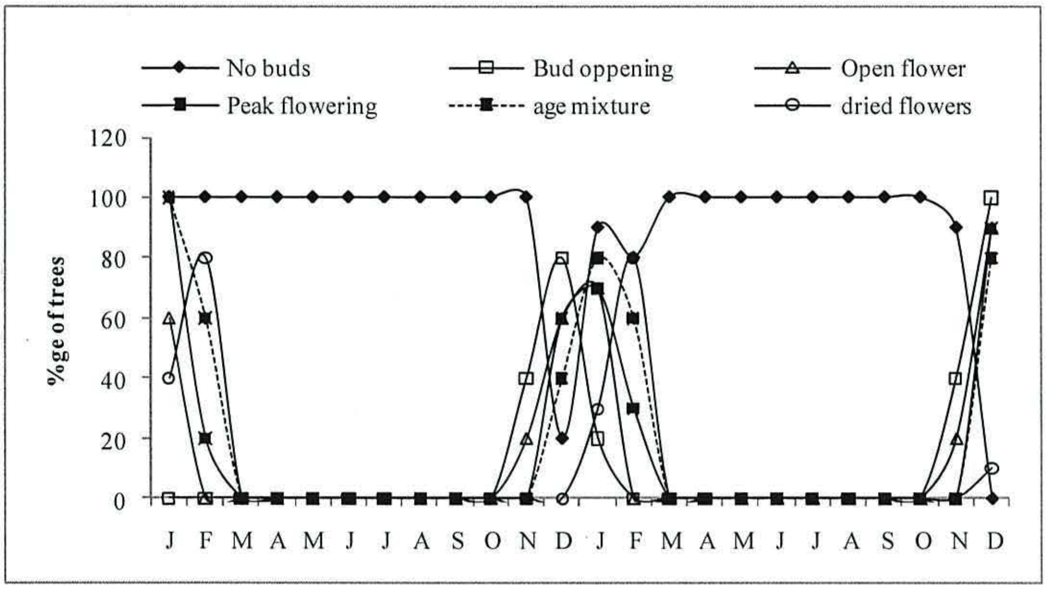

Figure 5. 28: Flowering phenophases for wild male subspecies *caffra* Jan 2008 - Dec 2009

(ix) Flowering of female trees for subspecies *birrea* in on farm environment

There were 20%, 30%, 30% and 70% of trees with open flowers, peak flowering, mixed age and dried flowers respectively. Next flowering season started in late October with 10% trees at bud breaking stage. The process peaked in November and December where there were 30% and 80% of trees at bud opening stage; 30% and 90% with open flowers; 10% and 90% at peak flowering and 10% and 70% with mixed age flowers in the respective months. In January 2009; 10%, 40%, 60% and 70% of the trees had open flowers, peak flowering, mixed age and dried flowers respectively. So January was the end of flowering and the next flowering season started later in October following a similar trend.

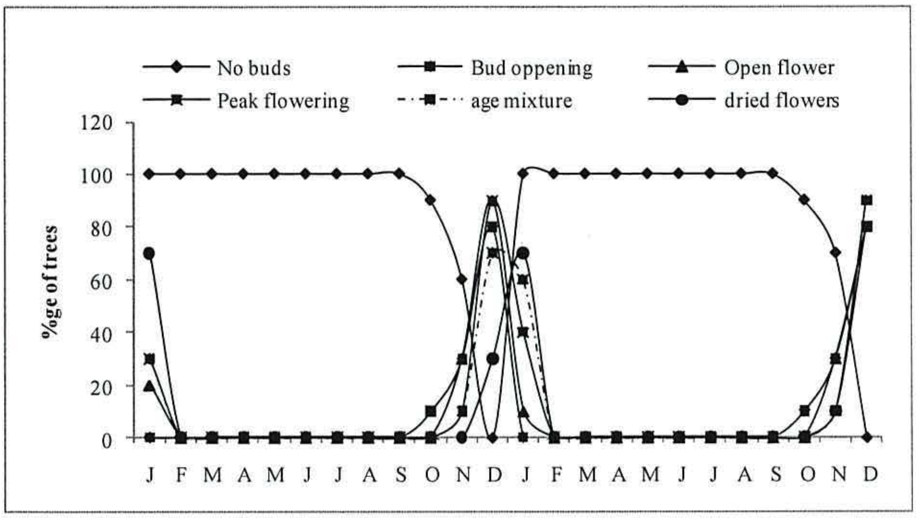

Figure 5. 29: Flowering phenophases for on farm female subspecies *birrea* Jan 2008 - Dec 2009

(x) Flowering of male trees for subspecies *birrea* in on farm environment

For the male trees in January 2008; 10%, 20%, 60% and 60% were at the stage of bud opening, flower opening, peak flowering, mixed age and drying respectively. The following season started in October with 10% of trees opening bud; and the flowering process continued for three months until January 2009 in all trees at different levels. In October 2009 another cycle of flowering started but this time there were more flowers in November. The results showed that unlike subspecies *multifoliolata* and *caffra*, flowering of males and females occurred during the same periods of time.

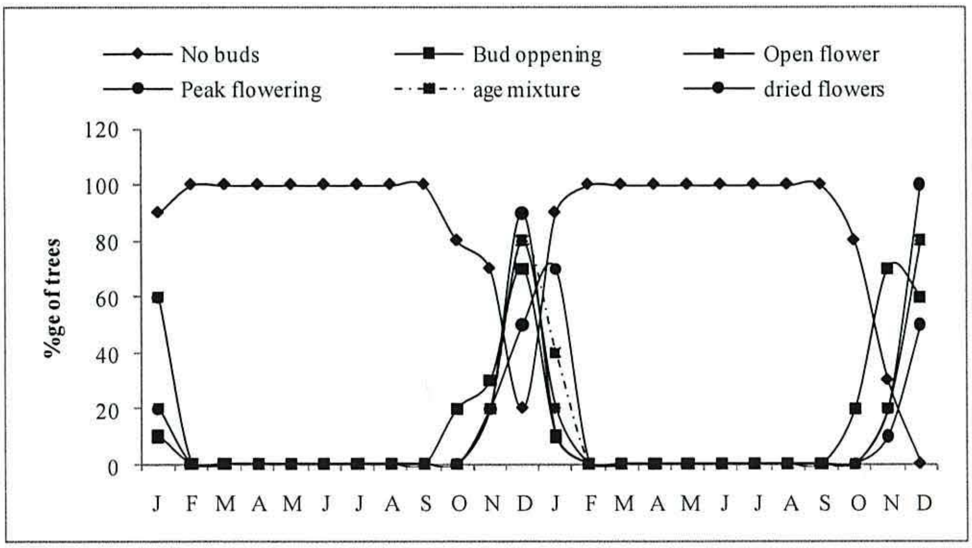

Figure 5. 30: Flowering phenophases for on farm male subspecies *birrea* Jan 2008 - Dec 2009

(xi) Flowering of female trees for subspecies *birrea* in wild environment

Flowering process was in the last stages in January 2008. The observed trees were at open flowers (10%), peak flowering (10%), mixed age (10%) and dry flowers (50%). In October 2009 the process started again and it was at the peak in December with 100% of the trees in the process of open flowers, peak flowering and age mixture. Flowering continued to January 2009 with up to 30% of the trees in the process. The cycle resumed again in October with a similar trend as the previous season.

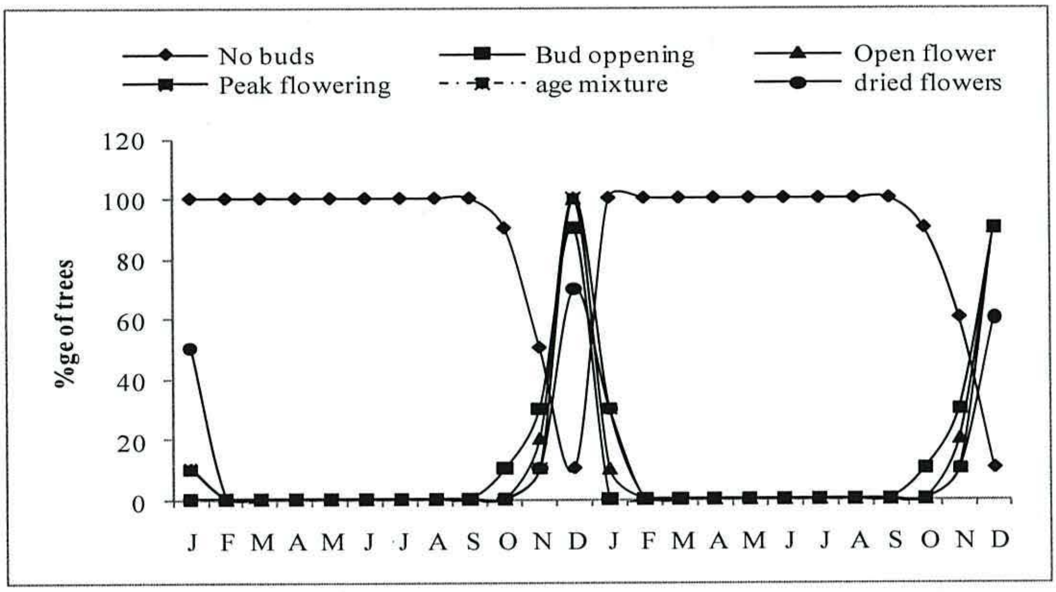

Figure 5. 31: Flowering phenophases for wild female subspecies *birrea* Jan 2008 - Dec 2009

(xii) Flowering of male trees for subspecies *birrea* in wild environment

Male flowering was observed in many trees than females with 50% of the males in the process compared to 10% of the females in January 2008. The following season started in October, same as the female population. All the trees were at various flowering stages in December and the process ended in January 2009 with 60% of the trees. Late 2009 flowering started in October with the processes peaking (90% of the trees) in December.

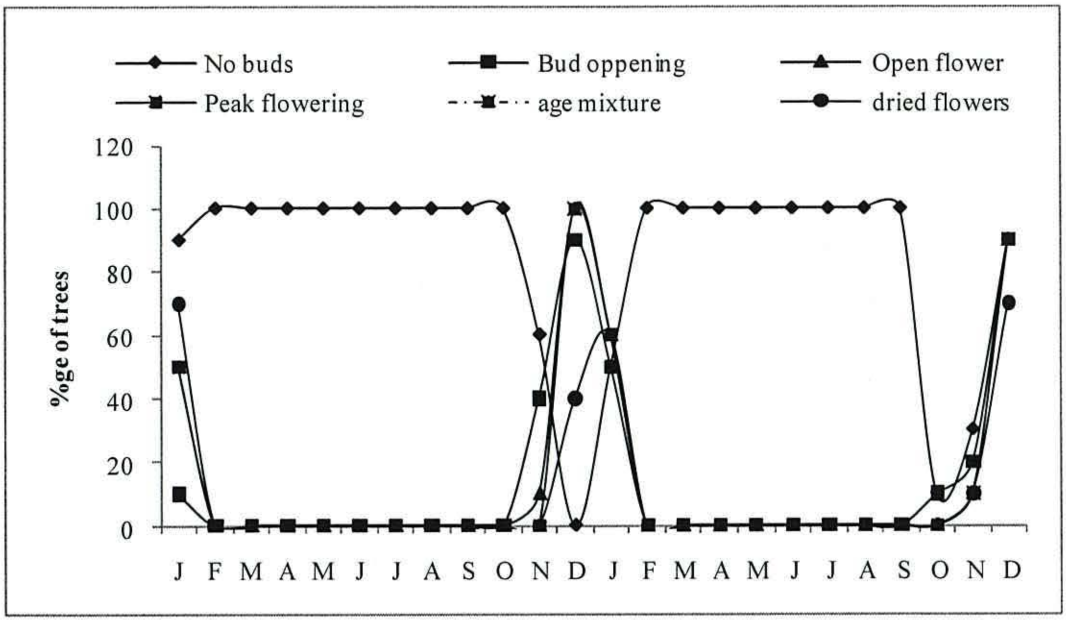

Figure 5. 32: Flowering phenophases for wild male subspecies *birrea* Jan 2008 - Dec 2009

5.3.5.3 Fruiting

i) Fruiting in subspecies *multifoliolata* in on farm environment

In January 2008, 70% of the trees were fruitless while 100% and 30% were at early fruit setting and green fruit stages respectively. In February 20%, 80% and 30% were at early fruit set, green fruit and mature fruit stage respectively; and there were no fruit setting process going on in March. Green fruit continue to be observed in March (90%) and April (40%) while mature fruit attained their peak in April and stayed on until July when 80% of the trees were at the end of fruit dropping stage. Fruit dropping which started in June with 40% of the trees was at the peak in July with 100% of the undergoing the process and it ended in August with 20% of the trees.

The fruitless period therefore started in mid August until January 2009 when green fruits started to develop. Early fruit set started in December and ended in February with 60% of the trees. Green fruits started in January, peaking in February and March, and ending in April with 70% of the trees. Fruit maturity was attained from March by 60% of the trees and 100% in April, continuing at this state until August where there were still 40% of the trees dropping fruits. Fruit dropping had started in May but it was slow because it was until July where 60% of the trees were fruitless and August where all of them were fruitless remaining so until the end of the year.

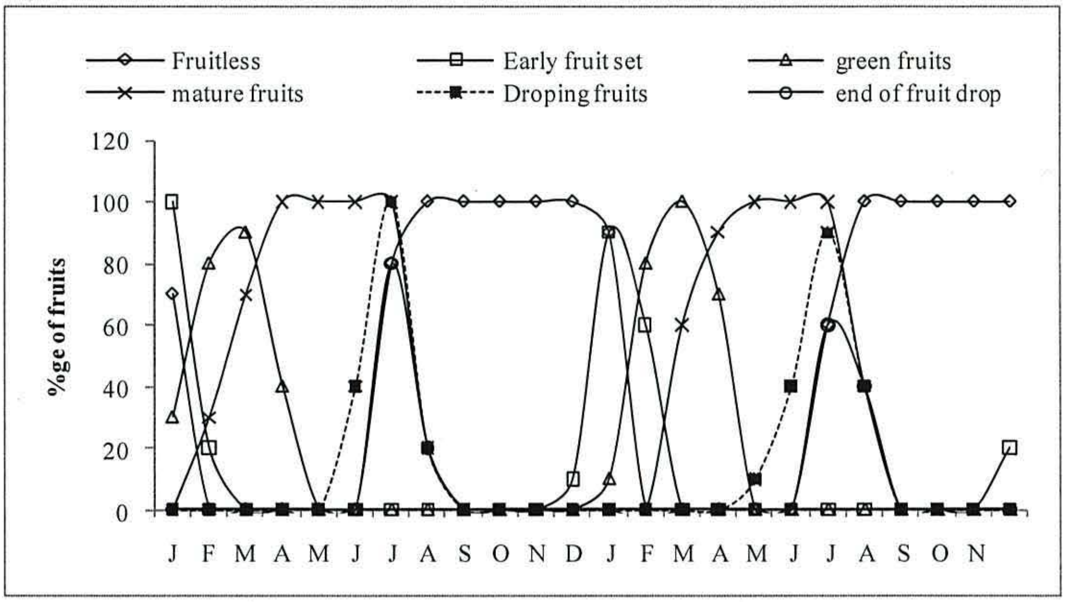

Figure 5. 33: Fruiting phenophases for on farm subspecies *multifoliolata* Jan 2008 - Dec 2009

(ii) Fruiting in subspecies *multifoliolata* in wild environment

The trend was more or less similar to the on farm populations. 80% of the trees were at fruit setting in January, lasting in February with 60% of the trees. Green fruits started in January, peaking in February and March at 80% before declining and ending with 30% of the trees in April. Fruits start to mature towards the end of February and in March all the trees had mature fruits until the beginning of August where 60% of the trees were observed to have finished dropping their fruits. Fruit dropping started in May and was high in June and July with 70% and 90% of the trees respectively, where in August 40% of the trees ended their dropping. Next fruit set begin in December peaking in January and ending in February. The trend was the same as the previous season except that few trees (10%) only had fruits in August compared to 40% in the past season.

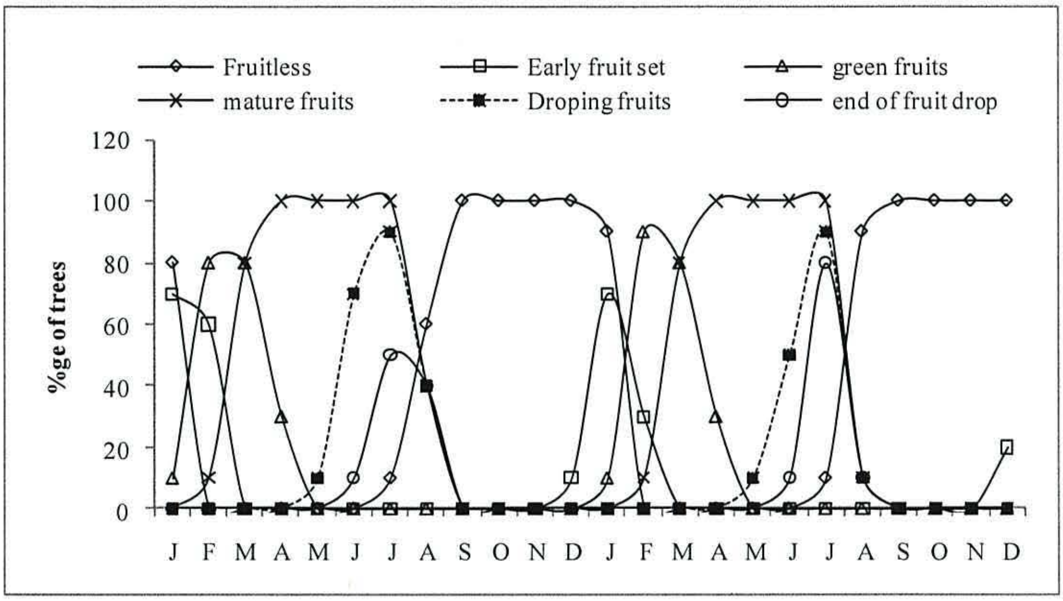

Figure 5. 34: Fruiting phenophases for wild subspecies *multifoliolata* Jan 2008 - Dec 2009

(iii) Fruiting in subspecies *caffra* in on farm environment

Fruiting was observed in January 2008 in 80% of the trees at the state of green fruits and early fruit setting and during this month 20% of the trees were still fruitless. Mature fruits were observed in 60% of the trees in February and by March all trees had mature fruits. They started dropping by the end of April and by May all the trees had dropped all their fruits. The next fruiting started in December with 20% of the trees at early fruiting and green fruits. In January 2009, 80% of the trees were at the stage of early fruit setting and developing green fruits and in February 40% of the trees were still at early fruiting and also another 40% with mature fruits while 60% had green fruits. Fruit dropping started in April with 40% of the trees becoming fruitless and the remaining 60% becoming fruitless in May. Fruiting resumed in December with 10% of the trees at the stage of early fruiting and green fruits development.

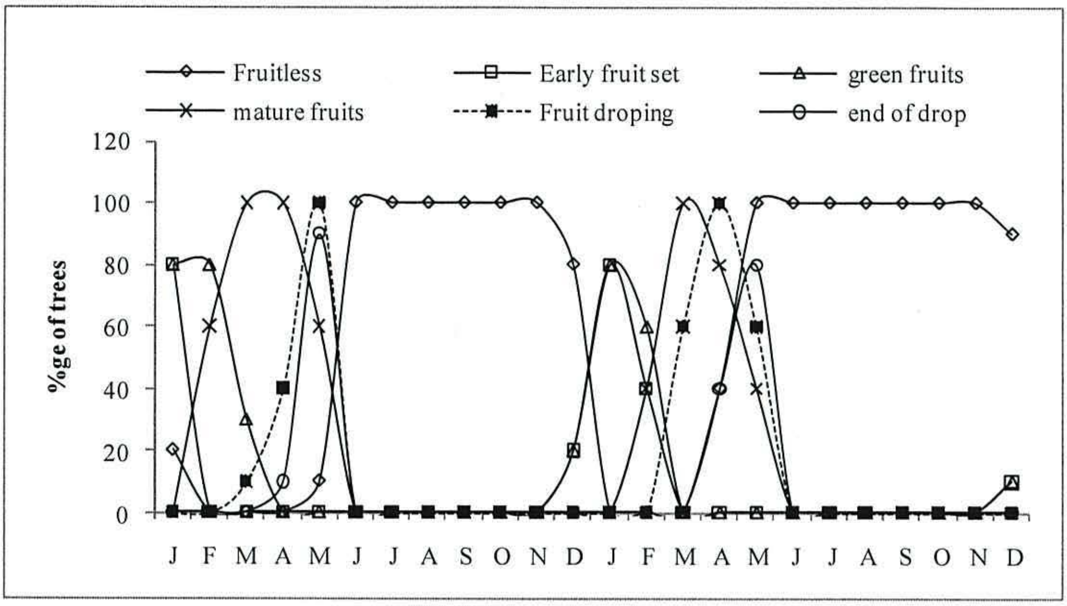

Figure 5. 35: Fruiting phenophases for on farm subspecies *caffra* Jan 2008 - Dec 2009

(iv) Fruiting in subspecies *caffra* in wild environment

For the wild trees, 40% of them were still fruitless, 80% at early fruiting and 60% with green fruits in January 2008. In February 30%, 80% and 60% were at early fruiting, green fruiting and mature fruits respectively. Mature fruits were observed in all trees in March and April with dropping also starting in April in 60% of the trees. In May 70% of the trees had remained with fruits and they dropped all of them in the same month. Fruiting commenced in December with 10% of the trees and increased in January 2009 where 70% and 30% of the trees were having early fruit set and green fruits respectively. Fruits started to mature in February in 60% of the trees and by March all of them had mature fruits. Dropping started in April in 80% of the trees and lasted in May with 50% of the trees. Another fruiting started in December with 20% of the trees at early fruiting.

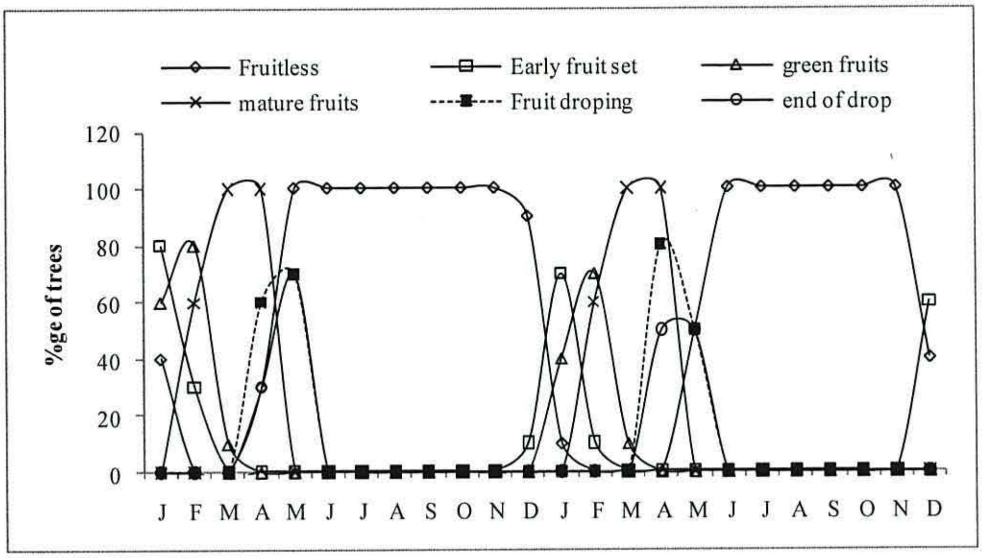

Figure 5. 36: Fruiting phenophases for wild subspecies *caffra* Jan 2008 - Dec 200

(v) Fruiting in subspecies *birrea* in on-farm environment

In January 2008 fruits were mainly mature with only 20% of the trees with green fruits. Fruit dropping started in February with 70% of the trees and lasted in March with 60% of the trees. The next season fruiting started in November with 30% of the fruits at early fruiting and fruiting was at the peak in December and January. Fruit dropping started in February in all trees and lasted in March with 30% of the trees. Another season started in a similar trend in November.

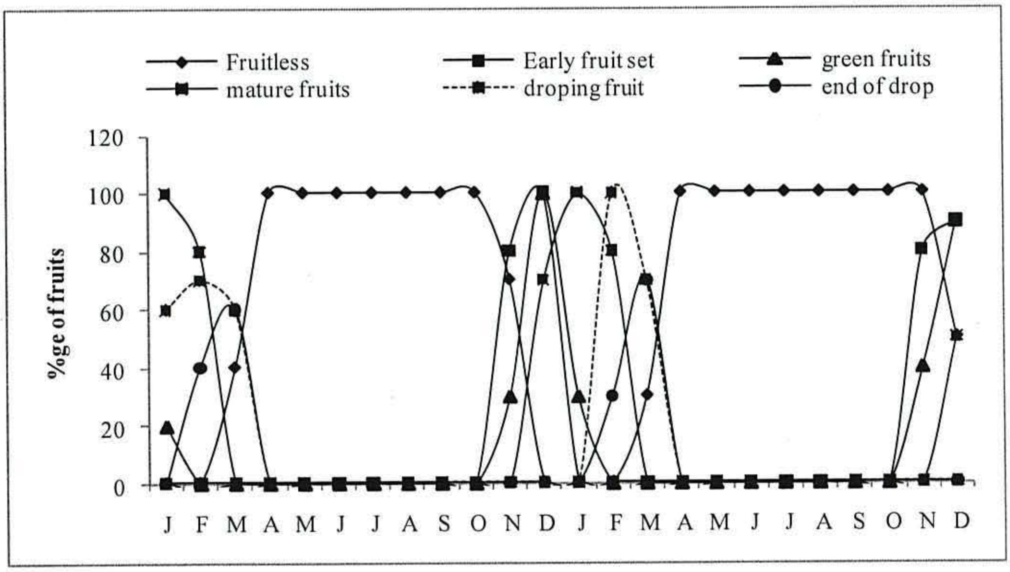

Figure 5. 37: Fruiting phenophases for on farm subspecies *birrea* Jan 2008 - Dec 200

(vi) Fruiting in subspecies *birrea* in on-farm environment

Green fruits were observed in 100% and 40% in January and February 2008 while also mature fruits were on 100% of the trees. All trees had mature fruits in February and March but dropping was also taking place and by end of March 30% of the trees were fruitless. The next fruiting commenced in November in 90% of the trees which had fruit setting and in January 80% had green fruits while 100% had mature fruits. So, all trees had mature fruits during January, February and March. Dropping started late February and lasted in March.

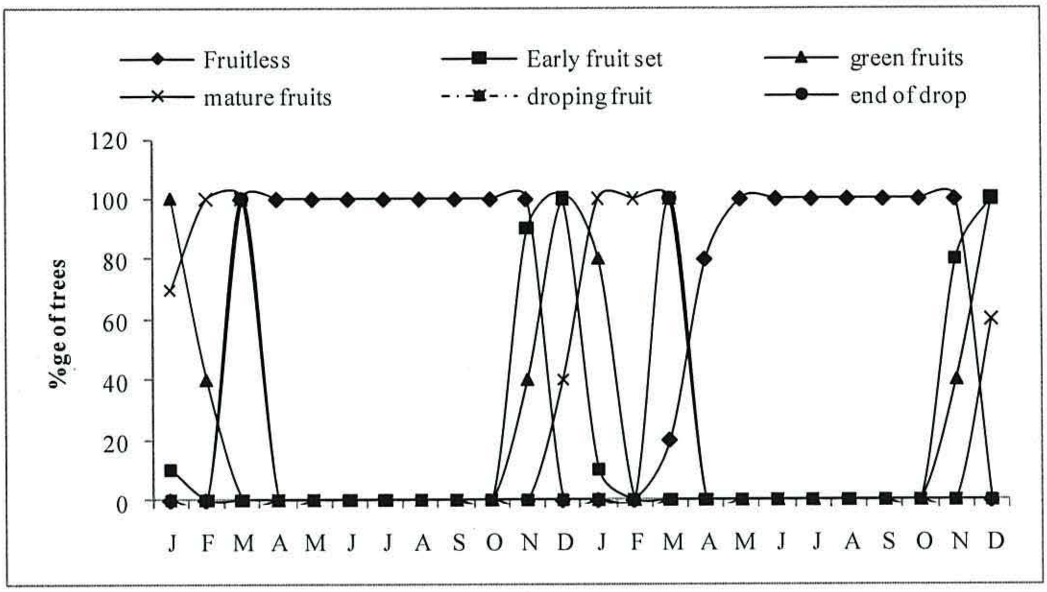

Figure 5. 38: Fruiting phenophases for wild subspecies *birrea* Jan 2008 - Dec 200

5.4 Discussion

5.4.1 Fruit phenotype

5.4.1.1 Fruit weight

A comparison between the subspecies showed that subspecies *multifoliolata* produced significantly the heaviest fruits followed by *birrea* and the lightest were fruits from subspecies *caffra*. It has been reported that fruit properties can vary within an individual, between individuals within a population and between populations of a species (Roach and Wulff, 1989). Various factors, biotic and abiotic ; influences the variation of fruit properties usually in complex interactions, needing long term studies to unravel particular causes for variation. Among the factors are also genetical

(Richings *et al.,* 2001; Tanksley, 2004) and allometric (Thompson and Rabinowitz, 1989; Leishman *et al.,* 1995; Cornelissen, 1999) properties. Subspecies *multifoliolata* trees were the biggest in size compared to *birrea* and *caffra*; and allometric analysis between crown diameter and DBH with fruit weight showed strong correlation - with crown size ($r = 0.66$; $p < 0.001$); with tree DBH ($r = 0.63$; $p < 0.001$). Big tree height, which normally influences crown diameter; and DBH have been found to relate to heavy weight of individual fruits in tropical drylands because of mechanical reasons (Peters *et al.,* 1988; Wolfe and Denton, 2001; Murray and Gill, 2001). However the impact of variability in genetical properties among the subspecies on fruit size should not be ruled out.

On farm fruits for subspecies *birrea* and *caffra* were heavier than the fruits from wild populations but the difference was not significant. However for subspecies *multifoliolata* it was the fruits from the wild population which were heavier and the difference was significant. Leakey *et al.* (2005) found that subspecies *caffra* trees on farm were significantly heavier than those from the wild in South Africa while tree in Namibia showed no significant difference by land use. Our results show one subspecies only (subspecies *multifoliolata*), with significant difference in fruit weight; and actually it was the wild fruits which were heavier. On farm fruits for *Sclerocarya birrea* are expected to be heavier than wild fruits due to farmers' selection pressure (Shackleton *et al.,* 2003; Leakey *et al.,* 2005); a phenomenon which have also been observed in fruits from other species (Tanksley, 2004). At the moment, the level of domestic utilisation and trade is less in Tanzania, hence probably the reason for the lack of the expected influence of farmers' selection pressure on fruit weight. On farm fruits are expected to be eavy not only due to selection pressure but also due to less competition and general care received from farmers (Bofa, 1999). However other factors such as intensity of pollination due to more tree hence pollen abundance (Kunin 1993; Ghazoul 2005), herbivory selection pressure (Wheelright, 1993) and soil water retention (Wolfe and Denton, 2001) which are superior in the wild environment as well as differences in biochemical processes within fruits (Richings *et al.,* 2001) may play an important role in giving opposite results.

Mean weight per fruit for the Tanzanian populations of *Sclerocarya birrea* was in the range between 30.11 ± 0.42 and 24.00 ± 0.29 g which were recorded from wild populations of subspecies *multifoliolata* and *caffra* respectively. The minimum (11.34 g) and maximum (47.70 g) fruit weight were both recorded from subspecies *multifoliolata*. Apart from a Namibian 'wonder tree' (Leakey *et al.*, 2005) and a clonal establishment in Israel (Hillman *et al.*, 2008) the mean fruit weight obtained for subspecies *multifoliolata* and *birrea* in Tanzania are higher than the previous records which are based on subspecies *caffra* from other countries. In an experimental stand established in Israel 34.41 ± 0.91 to 56.74 ± 1.65 g/fruit have been reported (Hillman *et al.*, 2008). Shackleton *et al.* (2003) reported mean fruit weight of 20.9 ± 0.18 g/fruit from on farm trees and 24.9 ± 0.19 g/fruit from wild trees of subspecies *caffra*. Leakey *et al.* (2005) report a mean weight of 26.7 g/fruit and 20.1 g/fruit for subspecies *caffra* in Namibia and South Africa respectively but also recorded a record breaking weight of 69 g/fruit from a tree he described as 'wonder tree' in Namibia of which its lightest fruit weighed 47 g.

Leakey *et al.* (2005) found that the main contributor of fruit weight for subspecies *caffra* is flesh, although several other factors interplay in the whole process of fruit development (Murray and Gill, 2001). For *Sclerocarya birrea*, fruit weight is an important factor in development of cultivars because it relates to flesh and kernel mass (Leakey *et al.*, 2005). The unique genetic variation for *Sclerocarya* in Tanzania (Kadu *et al.*, 2006; Mouk *et al.*, 2007) and the high fruit weight recorded from subspecies *multifoliolata* (also endemic to Tanzania) may spark more interest in research, domestication and conservation.

5.4.1.2 Fruit diameter

There was a significant variation of fruit size between the populations and between the environments. Subspecies *birrea* had the largest fruits followed by subspecies *multifoliolata* and the smallest fruits were from subspecies *caffra*. Pearson's correlation of fruit diameter and fruit weight was 0.239 ($P < 0.001$) meaning that the relationship was not so big and therefore a large fruit was not necessarily heavier than a small fruit. If the main contributor of fruit weight for the Tanzanian populations is flesh as is in South Africa and Namibia (Leakey *et al.*, 2005) it may imply that variable kernel sizes were responsible for irregularities in the relationship between weight and diameter. Fruit size is important because it relates to quality and appearance and hence influences the market and consumer satisfaction (Seymour *et al.*, 2002). For development of suitable cultivars it is therefore important to take both weight and size of the fruit into consideration. Fruit size, and not weight; was among farmers selection criteria for superior *Sclerocarya* trees hence when working with farmers this criteria needs to be modified to include weight.

For subspecies *birrea* on farm fruits were larger in diameter than wild fruits while for subspecies *caffra* and *multifoliolata* fruits from the wild populations were larger than those from on farm populations. Subspecies *birrea* (on farm) recorded the biggest mean size of 3.29 ± 0.03 cm while the smallest were subspecies *caffra* (on farm) with a diameter size of 2.85 ± 0.02 cm. Fruits from subspecies *multifoliolata* which were the heaviest were not the biggest probably because of the weak relationship between fruit weight and diameter. Most of the factors mentioned above which affect the variation of fruit weight between on farm and wild populations would be expected to also affect size in situations where normally fruit diameter and weight relates. But also in areas with frequent fires trees tend to produce small fruits in order to save energy to use for vegetative regeneration (Murray and Gill, 2001). This theory may also hold true for *Sclerocarya* because the site were subspecies *caffra*, whose fruits were smallest; was studied experiences frequent fires, highlighting the probability of its influence on fruit development. However these findings only shed some lights on the influence of fire on sizes of fruits from *Sclerocarya* trees, long term and wider area studies are necessary before a conclusion is made.

5.4.2 Fruit Yield

There was a significant difference in yield per tree between the subspecies but the difference in yield per tree between the two environments was only significant for subspecies *multifoliolata*. Subspecies *multifoliolata* and *caffra* recorded the highest and lowest yield respectively. Using data from the wild population in 2008 which recorded the highest yield per population; subspecies *multifoliolata* and *caffra* produced on average 6026 ± 1119 fruits/tree and 3021 ± 814 fruits/tree respectively. Across all the populations; the minimum yield was 229 fruits/tree (recorded from subspecies *caffra* on farm population in 2009 season) while the maximum yield was 13,046 fruits/tree (recorded from subspecies *multifoliolata* wild population in 2008 season). While there is no previous record on yield for subspecies *multifoliolata* and *birrea*; yield records for *caffra* from countries like Namibia and South Africa shows huge fluctuations between populations and seasons although most of the data is questioned for the scientific methods used (Shackleton *et al.,* 2003). Yields of 21,667 to 91,272 per 4 trees or 550 kg/tree (Quin, 1959); 9,601 fruits/tree or 270 kg/tree (Shone, 1979);. 2,000 fruits/tree or 550 kg/tree (Lewis 1987; Peters, 1988); 70,000 fruits/tree or 570 kg/tree (Roodt, 1988); 6,900 - 12,100 fruits/tree (Walker, 1989); 3,896 – 21,885 fruits/tree (MacHardy, 2003); 3,500 – 17,000 fruits/tree and 1,753 ± 343 fruits/tree or 36.8 ± 7.8 kg/tree (Shackleton *et al.,* 2005); and 6–45 kg/tree from clonal stands in Israel deserts (Hillman *et al.,* 2008) have been reported. The relationship between fruit yield and DBH was weak ($R^2 < 22$) similar to findings by Shackleton *et al.,* (2003), but there was a strong relationship between yield and crown diameter ($R^2 > 60$). Bigger trees are expected to produce more fruits but also environmental conditions such as soil properties, herbivory, pollination success and seasonal rainfall fluctuation affects yield of fruits (Bofa, 1999; Wolfe and Denton, 2001; Shackleton *et al.,* 2005).

There were more fruits from the wild than on farm populations but the difference was not significant with the exception of subspecies *multifoliolata.* The high yield of *S. multifoliolata* may relate to its habitat having a higher species richness compared to habitats of the other subspecies (Chapter 4). The production of more fruits in the wild than on farm population may relate to the availability of more pollinators in the wild and the high degree of tree isolation on farms (Lobo *et al.,* 2003; Waites & Ågren 2004). In presence of more pollinators, more flowers stand a high probability chance of fertilisation and therefore more fruits. Pollination intensity and pollination success increase with increasing population density and decrease with degree of isolation (Kunin 1993; Waites & Ågren 2004; Östergård & Ehrlén 2005; Singer & Wee 2005; Ward & Johnson 2005; Ghazoul 2005), However the previous single available data on yield by land use for subspecies *caffra* in S. Africa and Namibia by Shackleton *et al.,* (2003); McHardy (2003) and Leakey *et al.,* (2005) shows that on farm population produce significantly more fruits (>17, 000 fruits/tree) than wild populations (>3,500 fruits/tree). They attributed the findings to availability of more care by farmers and lack of competition from other plants on farmlands. Selection pressure by farmers is another factor they pointed out to be responsible for fruit production (Leakey *et al.,* 2005; Emanuel *et al.,* 2005) although it may not be reflected in this study because of the less utilisation of the fruits in Tanzania. However these findings highlights a need for more specific studies on the influence of competition, domestication care, selection and other factors on yield of *Sclerocarya birrea*. This could be done by studying more populations per each of the subspecies, hence addressing more on the human, habitat and marula population status dimensions.

Resource availability such as rainfall affects productivity of trees and forests (Chiarucci *et al.,* 1993; Ceballos *et al.,* 2004; Ågren *et al.,* 2008; Zunzunegui *et al.,* 2010). This was reflected in our results. With less rainfall in 2009, all the populations produced significantly less fruits compared to the previous year where rainfall was higher. Limited rainfall can result into abortion of flowers or fruits at their early stage in order allocate enough resources for few selected fruits (Winsor 1986, Sutherland 1986; Lobo *et al.,* 2003; Ågren *et al.,* 2008). Data on fruit yield is likely to vary from year to year in relation to the amount of rainfall available in particular years and especially during reproduction phase. Monitoring of yield may need to be done for several years in order to cover a wider range of rainfall fluctuations from year to year in a longer span.

5.4.3 Phenology

5.4.3.1 Leafing

Leaf phenology is important because it reflects the influence of evolution and environment on plant characteristics, and in turn has substantial implications for plant functioning (Singh and Kushwaha, 2005b). Variation in leafing was observed in relation to subspecies, land-use, seasonal and annual variation in rainfall and sex of trees. The variation was reflected on the onset, synchronisation and duration of bud break, flushing, new leaf development, leaf maturation and shedding. Duration of the overall leafing process for the population of the three subspecies was between six to eight months beginning generally in October and November and lasting in June to August.

Subspecies *birrea* started leafing earlier (October) than *multifoliolata* and *caffra* (November/December). However, subsp. *caffra* finish leaf shedding later (August) than *birrea* (June) and *multifoliolata* (July). Subspecies *birrea* leafing took place just before or at the beginning of rainfall while *caffra* and *multifoliolata* started weeks to a month after the rainfall season. Across the subspecies it is seen that leaves are shed during the early dry or cold season and new shoots emerge after the onset of the wet season. Some authors have reported that tropical trees start leafing at the onset of rain season (Reich and Borchert, 1984, van Shaick *et al.,* 1993) while others point out that there are a good number of trees which leaf during the peak of dry season (Elliot *et al.,* 2006). Although the phenological patterns are mainly guided by availability of water (Dhief, 2009) as well as weather and photoperiod (Selwyn and Parthasarathy, 2006) the differences in timing of the events between populations or species may be due to other factors and in many situations it becomes complex to relate them to a single factor (Borchert *et al.,* 2002). Holili, where rainfall is bimodal; receives short rains during October to December, followed by a dry spell in January and heavy rains during late February to April or May. Kiegea and Malinzanga are unimodal with the heaviest rains experienced between February and May (TMA, 2010) and our results observed the same but with small amounts of rainfall starting as early as October. The leafing of the subspecies may be an adaptation to rainfall patterns with subspecies *birrea* leafing early to manage to pass through the dry spell of January. It is reported that for *Sclerocarya,* leafing start at the beginning of rains and shed leaves in the dry season (Hall *et al.,* 2002). The early leafing of subspecies *birrea* is in line with previous suggestions (Bie *et al.,* 1998; Munjuga, 2000) that in areas with bimodal rain system *Sclerocarya* starts leafing at the end of the long dry season.

Timing and duration of flushing and leaf development may be controlled by many factors. The timing of leafing can be a compromise between exploiting the most favourable environmental conditions and avoidance of herbivory. In many cases, herbivory may simply be avoided by the satiation effect of synchronous flushing (Fenner, 1998). Shedding of leaves for deciduous plants is a response to water stress (Lobo *et al.,* 2003) where plants hibernate and forego photosynthesis to avoid excessive loss of water through transpiration. Although not all species will necessarily respond to this theory (Loubry, 1994), *Sclerocarya birrea* leaf flushing was synchronised and shedding responded to water stress.

Leafing phenophases for all the subspecies responded to rainfall shortages which were experienced in 2009. There was more synchronisation of leafing phenophases compared to the year were rainfall was high. For instance flushing for subsp. *multifoliolata* took a shorter duration while new leaf stage took a longer duration, hence coinciding with mature leaf stage, in the year when rainfall was less but the final events, especially shedding timing, was rapid. For the other subspecies; flushing, new leaf and mature leaf stages took place more simultaneously for a long time during the low rainfall year. Among other factors, leafing events depend upon precipitation and soil water availability (Murali and Sukumar, 1994; Kushwaha and Singh, 2005b) and plants have adapted to water stress and other limiting factors by synchronising leafing events (Lobo *et al.,* 2003). Previous work on *Sclerocarya* reports that more rainfall (> 800 mm) shortens leafless period for up to 3 months while less rainfall increases leafless period for up to 8 months (Hall-Martin & Fuller, 1975; Storrs, 1979, Teichman, 1982; Hall *et al.,* 2002). Rapid shedding of leaves in the second study season (2009) might have been caused by low rainfall.

On farm trees had a prolonged leaf season than the wild trees. On farm trees started leafing early but shedding for both on farm and wild trees was simultaneous. This may result from the influence of farmland management activities (Williams *et al.,* 1997; Bofa, 1999) and synchronisation to cope with herbivory, and competition for resources especially water (Brochert *et al.,* 2002) in the wild. While the trees on farm enjoy husbandry from farmers and less competition from other trees, those in the wild are faced with much more severe competition for nutrients and water resources. Also the availability of nutrients which are essential for plant development especially nitrogen may be enhanced by farmers management of land creating more favourable conditions for the trees on farms. Other advantages which favour on farm populations include weeding and escape from severe wild fires (Williams *et al.,* 1997; Bofa, 1999). However due to many factors which controls phenology it is always difficult to correlate which factors are mostly responsible for the pattern of specific phenological events (Borchert *et al.,* 2002). Phenology of different species at different environments is reported to respond differently on fire, silvicultural practices and soil nutrient variations (Bofa, 1999; Singh and Kushwaha, 2005b).

Male trees from all the subspecies started leafing later than female trees. This means that the leafing duration for male trees was shorter than that of female trees. Females of dioecious plant species usually tend to develop higher reproductive effort than males because they produce seeds, fruits, and associated structures in addition to flowers (Wheelwright and Logan, 2004), and thus they have to invest and allocate more biomass resources to reproduction (Correia and Barradas, 2000, Guangxiu, 2009). Therefore females of these plants have evolved a means of investing in production of more carbon to support the reproductive costs (Varga and Kytöviita, 2010). Female plants have been found to photosynthesise more than males. Jing *et al.* (2008) found that net photosynthetic rate (*Pn*) of female *Ginkgo biloba* was significantly higher than males. Montesinos *et al.* (2010) points out that fertility may be reduced if resources such as water and nutrients are limited. Therefore the tendency of *Sclerocarya birrea* female plants leafing early than males may be an adoptive ecophysiology mechanism to bear leaves for longer times in order to maximise photosynthesis.

5.4.3.2 Flowering

This study have revealed that flowering of *Sclerocarya birrea*, as is leafing, took place at the end of dry season or the beginning of rain season. The duration of flowering was between 50 to 90 days at the community level but for individual trees it lasted up to a month. This flowering duration is in line with the results by Devineau (1999) who worked on subspecies *birrea* in Burkina Faso. Flowering of subspecies *caffra* and *multifoliolata* occurred a week to a month after the first rains while subspecies *birrea* flowering occurred at the transition of dry and wet season. It have been reported that seasonally dry tropical forests flowering is often concentrated in the transition from the late dry to the early wet season (Murali & Sukumar 1994), same as it was found in subspecies *birrea*. Past reports had indicated that flowering occurs during the dry season for subspecies *birrea* and *caffra* with exception of populations in bimodal rainfall areas and the onset vary through years depending on weather fluctuations (Hall *et al.*, 2002).

The differences observed in flowering phenophases were mainly in terms of subspecies and sex; rather than whether they occurred on farm or in the wild. Therefore the habitat condition between on farm and wild environment did not happen to influence flowering of *Sclerocarya birrea*, unlike leafing. Subspecies *multifoliolata* and *birrea* started flowering in October while *caffra* started in November. But the flowering duration of subspecies *birrea* was shorter while that of subspecies *multifoliolata* was longer such that drying phase coincide with that of subspecies *caffra* which started flowering a month later. Physiologically, flower production and maintenance requires the expenditure of energy to form non-photosynthetic tissue and nectar, the cost of which is considerable (Ashman & Schoen 1997, Obeso, 2002). The dry spell during the month of January faced by subspecies *birrea* may be the reason behind its shortest flowering phenophases compared to the other subspecies. This is because the trees of subspecies *birrea* would need to conserve energy to survive through the water stress period while at the same time developing fruits.

With the exception of subspecies *birrea* within which there was no variation in flowering between male and female plants, male flowers for subspicies *caffra* and *multifoliolata* were found to flower early and dry late compared to female flowers. This condition probably ensures that during the life of all female flowers availability of pollen is ensured. It may also be a requirement of female plants to conserve energy for fruit production (Correia and Barradas, 2000, Guangxiu, 2009), a responsibility which the male plants do not have. However subspecies *birrea* did not show differences between male and female flowering phases, most probably because its flowering phase was for a shorter duration compared to the other subspecies.

5.4.3.3 Fruiting

Fruiting duration was longest for subspecies *multifoliolata* taking up to 8 months and shortest duration was for subspecies *birrea* (3 to 4 months). Fruiting of subspecies *birrea* in Burkina Faso has been recorded to last for up to 7 months (Devineau, 1999) while McHardy (2003) reported fruiting period of 27 to 68 days for some individuals of subspecies *caffra* in South Africa.

The bimodal nature of rainfall in Holili which involve a dry spell during the fruiting phenophase may be the reason for short life span of fruiting of subspecies *birrea* while the high amount of rainfall available from February to late May in Malinzanga relieves water stress on the populations of subspecies *multifoliolata*. It is reported that fruiting areas with shortened rainfall period in the tropics have a short fruiting duration (3-4 months) while hose with prolonged rainfall periods have a longer duration of 7-8 months (Singh and Kushwaha, 2006). Precipitation is an important factor in phenology (Murali and Sukumar, 1994) because it influence availability of water resources for fruit maturation (Ågren *et al.,* 2008) and therefore over time plants have evolved phenological events that coincide with local climatic conditions (Singh and Kushwaha, 2005a). Also in Malinzanga temperatures were relatively low (20 ^{o}C) compared to Kiegea and Holili (both > 24 ^{o}C) and might have influenced the rate of growth of fruits. The low temperatures may also lead to a decreased loss of water from the trees and soil surface. The seasonality of tropical tree phenology is mainly determined by the duration and intensity of the dry season (Mooney *et al.,* 1995) and therefore conspecific trees often will have different ways to respond phenologically in accordance to local climate (Frankie *et al.,* 1974; Singh and Kushwaha, 2005a).

There were no differences in fruiting phenology between on farm and wild populations, and it followed the flowering phenology with trees which flowered earlier bearing fruits earlier. Similar results were reported by McHardy (2002) where he found no considerable difference in fruiting between trees on rangelands and those on homesteads for subspecies *caffra*. Again the influence of land and tree husbandry did not appear to affect the timing of fruiting phenology of *Sclerocarya birrea*. This is contrary to other reports where fire incidents, farming practices such as pruning and looping, soil properties and density dependent factors such as competition for pollinators and avoidance of herbivory are said to be among the main factors which shape the variation of fruiting in populations found in cultivated compared to natural environments (Bofa, 1999; Ågren *et al.,* 2008).

Depending on the intensity and frequency of burning on dryland forests or on farmlands during land preparation, some species would synchronise flowering and hence fruiting (Bishop and Schemske, 1998, Boffa, 1999); increase or decrease fruiting (Kaye *et al.,* 2001); or the burning may cause drying of soil surface and affect soil nutrient relations and hence availability of water and nutrients to plants (Bofa, 1999) which in turn may affect fruiting phenology. Farming activities such as fertilisation, weeding, looping and pruning have been found to influence fruiting phenology of some species (Bofa, 1999). Soil nutrients such as nitrogen are important in plant nutrition and any variation in nutrient content between on farm and wild environment may consequently be reflected on fruiting and other phonological events. There was no meaningful difference in soil properties, with the exception of organic carbon content, between on farm and wild environments where *Sclerocarya* was studied (Chapter 4). This perhaps may have implications in the lack of variation in fruiting events we observed between the two environments.

On the other hand, in the wild areas, insect and bird pollinated species will tend to flower early before heavy leafing for easy attraction of pollinators but also have evolved a synchronisation of fruiting to minimize seed predation (Murali and Sukumar, 1994) while lack of enough pollinators on farms may result in slowed rate of pollination (Bishop and Schemske, 1998). Therefore we would expect sporadic fruiting on farms than in the wild land-use, but this was not the case.

The above discussion shows that in most cases fruiting as would be other pheonological events is expected to at least express some notable variation depending on land use. Nevertheless phylogenetic checks are understood to be stronger than localised ecological events in shaping phenological patterns (Kochmer and Handel, 1986) and therefore any on farm and wild variation in habitat conditions can easily be masked. Results from this study showed no variation in fruiting between the two land-uses suggesting that probably phylogenetic reasons outweighed local ecological forces. However this explanation can only shed lights on probable causes for the observed phenology because it is difficult to ascertain the specific causes of phenological patterns. To unravel the specific explanations for the phenology observed in *Sclerocarya birrea* between on farm and wild population we may need more detailed and long term assessments.

CHAPTER SIX: VEGETATIVE PROPAGATION OF *SCLEROCARYA BIRREA*

6.1 Introduction

6.1.1 Background information

The problems of poverty, diseases, climate change, land degradation and overuse of natural resources among others are interlinked and often requiring holistic approaches to solve. In the dry land areas of sub-Saharan Africa in general poverty and deforestation have become persistent problems challenging research and development practitioners for decades. It has been suggested that enabling poor farmers in this region to domesticate useful multipurpose indigenous fruit trees could result into a big contribution towards solving the above problems through supplementing food requirements, improve income generation while conserving and improving the populations of the trees which are becoming threatened (Tchoundjeu *et al.*, undated; Akinifesi *et al.,* 2006; Teklehaimanot, 2008). This intervention can best be achieved through agroforestry techniques where farmers can combine crop plants and fruit trees for income and food purposes.

However among the most important challenges associated with agroforestry technologies is the multiplication on a large scale of the required fruit trees (Leakey and Tchoundjeu, 2001; ICRAF, 2002), especially so on indigenous than it is for exotic species. The ordinary manner by which plants multiply in nature is propagation by seed (Haq *et al.,* 2008). But for improved and quick domestication of wild species, vegetative propagation methods present a number of advantages, most importantly the production of an exact copy of the genome of a mother plant and reduction of juvenile periods which is a major setback of indigenous fruit trees (Akinnifesi *et al.,* 2008).

Vegetative propagation is also important where plants have irregular flowering and erratic fruiting, lack viable seeds (Wojtuski *et al.,* 1993; Leakey and Newton, 1994; Leakey *et al.,* 1994; Nketiah *et al.,* 1997) and trees are overexploited (Kouakou, 2009). Vegetative propagation is achievable since plants, unlike animals or humans possess meristematic, undifferentiated cells that can differentiate to the various organs essential in forming a complete new plant (Kerstettera and Hake, 1997; Glover, 2000). A piece of plant shoot, root, or leaf, can therefore, grow to form a new plant that contains the exact genetic information of its source plant (Amri, 2010). For example, in wild populations, a large variation in important features like fruit quality and quantity may be expressed and desired for particular goals. It would therefore be advantageous to propagate these individuals vegetatively to capture the genetic variation expressed, which may otherwise get lost or weakened through sexual propagation (ICRAF, 2002). In absence of sexual reproduction by seeds, opportunity for variation and evolutionary advancement is denied. However, vegetative propagation is superior in identical plant reproduction with desirable features such as high productivity, superior quality, or high tolerance to biotic and/or abiotic stresses, and as such, plays a very important role in continuing a preferred trait from one generation to the next (Akinnifesi *et al.,* 2008).

Vegetative propagation methods have been developed and used for centuries particularly in temperate regions (Leakey, 1985). Tropical fruit species have been subjected to vegetative propagation in a number of cases that have created a lucrative export market especially citrus, mango, avocado, and macadamia nut (Simons and Leakey, 2004). Tropical timber trees have also been cloned, mainly for plantations where uniform trees are needed (Nketiah *et al.,* 1997). Many indigenous trees with high monetary potential or nutritional value are so far only used from natural stands. By integrating these high value trees into agroforestry systems, smallholder farmers in the tropics could greatly benefit while rescuing the wild populations from dangers of local extinction. Vegetative propagation is seen as a possibility to select superior germplasm, bring this important resource into the farmers' fields and reduce the usually frustrating long maturation period (ICRAF, 2002).

Discovery of valuable non wood forest products and subsequent extraction from wild tree resources has led to over-exploitation rather than sustainable use leading to a boom and bust cycle of utilisation of natural resources (Prance, 1994). It has been reported that wild fruit trees in the miombo woodlands are disappearing very fast. Population growth, poverty and decline in food crop yields have intensified the demand for land and wild fruits. The intensity of this demand pressure is so high that it is posing threats of extinction of indigenous fruit trees along with the associated valuable gene pool (Chimwala, 2004; Tchoundjeu *et al.,* 2004; Akinnifesi *et al.,* 2005; Akinnifesi *et al.,* 2006, Akinnifesi *et al.,* 2008). Two examples of valuable indigenous fruit species potential as *'tree revolution'* candidates for domestication, are *Sclerocarya birrea* and *Uapaka kirkiana*(Leakey, 1997; Teklehaimanot, 2008). Already there are reports that

Uapaca kirkiana populations are rapidly declining in Malawi due to overuse. For *Sclerocarya birrea* reports on declining wild populations (probably due to over-collection of fruits) in Namibia are available (Shackleton *et al.,* 2005) while destruction by wildlife are also affecting regeneration in South Africa (Hemborg and Bond, 2006). Incorporating the trees in domestication programs through the use of vegetative propagation techniques is suggested to be among the best ways to minimise pressure on wild resources, increase yield, and conserve important gene pools as well as rescuing the trees from dangers of extinction. Several methods for vegetative propagation are available but for indigenous trees of Africa there are challenges in identifying the most suitable and cost effective vegetative propagation method for particular species (Akinnifesi *et al.,* 2006; Amri, 2010).

Sclerocarya birrea has been identified as a priority indigenous fruit trees for improvement of livelihoods in Eastern and Southern Africa and ranks number one in Tanzania (Teklehaimanot, 2008). It is reported that *Sclerocarya birrea* can be propagated by grafting, cuttings, marcoting and truncheons (Shone, 1979; Holtzhausen *et al.,* 1980; Lars and Marina, 2000; Hall *et al.,* 2002, Maruzane *et al.,* 2002; Shackleton *et al.,* 2002; ICRAF, online). However there are contradicting reports on feasibility and levels of success in propagating *S. birrea* by the different methods. For example; Mng'omba *et al.* (2008) and Kimondo (2010) report that propagation of *S. birrea* by cuttings is not possible but Holtzhausen (1990) managed to root cuttings of *S. birrea* in South Africa. Akinnifesi *et al.* (2005) reports grafting success of 52 – 80 % for *Sclerocarya birrea* while Akinnifesi *et al.* (2008) reported that cuttings and air layering failed to root. Gerhardt and Nontokozo (2005) report propagation from seeds with 60% germination success in Zimbabwe although the detailed methods, especially of seed pre-treatment are not given. Germination of seeds needs pretreatment (Hall *et al.*, 2002) but other reports say there is no need of pre treatment (Taylor *et al.,* 1996). Field performance of grafted plants of *Sclerocarya birrea* is reported to be both high (Akinnifesi *et al.,* 2006) and low (Akinnifesi *et al.,* 2004; Akinnifesi *et al.,* 2008) based on location, but its juvenility can be reduced from 8 to 4 years (Taylor *et al.,* 1996). In the 1990s, large numbers of unimproved seedlings of *Sclerocarya birrea* were distributed to farmers as one of the efforts to establish the tree on farms as an agroforestry species in southern Africa. This early enthusiasm was short-lived as graft-take became as low as 10% (Jaenicke *et al.,* 2001) and low survival and growth were reported on farmers' fields (Mhango & Akinnifesi, 2001).

Sclerocarya birrea can also be propagated from truncheons but the method is said to have no commercial applications. More recently a micropropagation of *S. birrea* has been conducted successfully through induction and development of nodular meristemoids from leaf explants (Moyo *et al.,* 2009). Lack of knowledge on reliable propagation methods has slowed down domestication of many IFTs in Africa (Akinnifesi *et al.,* 2008; Amri, 2010). In addition, the overexploitation of *Sclerocarya birrea* from natural stands for carving wood and fruits is reported to threaten the species (Shackleton *et al.,* 2002). This exacerbates the problem for species which have poor seed viability and meager distribution.

While some breakthroughs have been recorded in propagating *Sclerocarya birrea* in southern Africa (Akinnifesi *et al.,* 2006; Chirwa *et al.,* 2007), there is a crucial contradiction about the best and appropriate methods. According to Akinnifesi *et al.* (2006), lack of knowledge on reliable propagation methods has slowed down domestication of many IFTs. For instance while some researchers are reporting *Sclerocarya birrea* to successfully propagates from cuttings, others claims failure of rooting from cuttings. Where success is reported, the techniques used involve materials and methods which are relatively technical and too costly to handle by poor farmers. Since in the end the farmers are the ones with the responsibility of domestication, development of a simple and cheap vegetative propagation technology will make a huge contribution (Amri, 2010). Tanzania is the centre of diversity for *Sclerocarya birrea* and therefore harbors a valuable gene pool reservoir. Successful domestication programs in Tanzania will not only help to alleviate poverty and food scarcity but will significantly contribute to conservation of the species genetic diversity.

6.1.2 Objectives and hypotheses

The main objective of this study was to develop efficient and low technology vegetative propagation method for *Sclerocarya birrea.*

Specifically;

- To use farmers superior tree selection criteria to identify sources of germplasm collection for the vegetative propagation studies

- Using three vegetative propagation methods namely cuttings, air layering and grafting to evaluate and identify a technically and economically better means of propagation by small holder farmers

To address the above objectives, the following hypotheses were tested:

- *Sclerocarya birrea* cannot be vegetatively propagated by cuttings, air layering and grafting
- Different grafting techniques do not influence the performance of grafted seedlings
- Different sizes of scions used in grafting do not influence performance of grafting seedlings regardless of the grafting technique used

6.2 Methodology

6.2.1 Vegetative propagation by stem cuttings

The study was carried out at the Sokoine University of Agriculture horticulture nursery in Morogoro between December 2007 and December 2008. Stem cuttings for vegetative propagation experiment were collected from mature and healthy trees using farmers' selection criteria of superior trees, which were trees with big crowns and DBH; in Kiegea, Morogoro. In order to maintain their freshness, cuttings were collected and wrapped in wet hessian rags (Mwangingo *et al.,* 2002), transported, processed and planted on the same day. No rooting hormones were used because they are scarce in Tanzanian retail shops with many people ordering them from Nairobi. Since the prime goal of this work was to find a practical and affordable means of propagation to farmers, the use of hormones was regarded as unsuitable option.

Three factors were investigated: season of cutting collection, nodal position of the cutting (basal and terminal) and type of rooting media. The seasons assessed were during the wet season (December) when *Sclerocarya birrea* trees are flushing and towards the end of dry season (October) when the trees have accumulated energy through shedding season. The nodal positions assessed were the base/middle part of a small branch and the terminal or distal part of the same branch. Branches of 30 - 40 cm length were cut and divided into two equal halves (the basal and the terminal). For the terminal cuttings the leaves were trimmed to leave two semi-trimmed leaves.

The cuttings were then raised in a non mist propagator for rooting. The non mist propagator was a modification of the ones described by Leakey *et al.* (1990); Longman (1993) and used by Mwang'ingo *et al.* (2002). All the sides including the lid frame were covered by polythene sheets firmly fastened to wooden frames, where the lid was a transparent sheet and the sides were blue. Five propagators were made containing 8 sections of 50 x 50 cm making a total of 40 separate chambers. The propagators were placed under a shade to reduce the light intensity and direct sun heat (Plate 6.1). The chambers were filled with gravel and stones for up to 20 cm height and the top 20 cm were filled with particular type of rooting media. Five different types of media were used and replicated times four. The media types were forest soil, soil from *Sclerocarya* stands (mycorhiza soil), rice bran, saw dust and sand. The rooting media were treated by solarisation for two weeks before they were put into the propagator.

A total of 16 cuttings were planted in each chamber, 8 basal pieces and 8 terminal pieces. Watering was done every morning after two days but mist spraying was done 3 times during daytime at intervals of 3 hours to maintain a high relative humidity inside the propagators.

Plate 6. 1: Non mist propagators used in rooting of *S. birrea* cuttings

The mist spray was done at 10.00 am, 1.00 pm and 4 pm everyday. Inspection was done on daily basis in the morning to observe any changes in the cuttings while rooting was inspected by removing the cuttings after 5 weeks. After the first rooting inspection, the following inspections were done every other week. The rooting experiment was done in December 2007 and repeated in October 2008.

6.2.2 Vegetative propagation by air layering (marcotting)

The marcoting work was done in three sites which are Malinzanga in Iringa, Kiegea in Morogoro and Holili in Kilimanjaro. The aim was to assess the season with the most rooting success of the marcots as well as comparing rooting performances of the three subspecies. Air layering was conducted in 10 male and 10 female trees for each subspecies and from each tree 10 branches measuring 5 to 15 mm wide were randomly selected and used for marcotting. At somewhere in the middle of the branch a ring of the bark about 1 inch long was removed to expose the cambium (Mwangingo, 2002). The exposed cambium was surrounded with damp decomposed sawdust and wrapped in transparent polythene sheet fixed at the terminals with an electrician tape (Plate 6.2). Inspection was done every week and water added using a vet syringe when deemed necessary while observing if roots have developed on the walls of the polythene cover. After 10 weeks the marcots were removed for final inspection of rooting. The experiment was done twice; during the onset of wet season where the trees were becoming vegetatively active and at the end of wet season using saw dust as a rooting media.

Plate 6. 2: Air layering/marcotting

6.2.3 Vegetative propagation by grafting

The experiment was done in Morogoro in order to enable frequent and close monitoring. Naturally regenerated seedlings were used as rootstock. A survey of naturally established seedlings was done to identify an area with a high abundance of seedlings regenerated from seeds (and not coppices or sprouts) in farmers' fields in Kiegea. Seedlings from coppices or sprouts were not used because practically they will need farmers to cut down trees to obtain root stock.

We aimed at grafting 20 scions (5 - 10 mm thick) and 20 scions (11 – 20 mm thick) using two methods, whip and tongue and top wedge grafting; and therefore we selected 80 naturally regenerated root stocks. The root stocks were 5 - 20 mm thick and at least 30 cm tall. No treatment or fertilization was done on the grafting and they were not covered with polythene paper as it is usually done. This risk was taken to avoid drawing attention from children and even adults that out of curiosity might disturb or destroy the experiment . Grafting was done in January during bud-break using scion from tips of branches.

A sharp knife was used in the preparation of the root stock and scion and was wiped with a cotton wool soaked in spirit after every specimen to sterilize it from contaminating the union with any impurities from the preceding specimen. The knife was sharpened every after five specimens using a stone knife sharpener to maintain its sharpness so that the adjoining cambium and other cells are not destroyed. Special measures to avoid dehydration of the scions were considered. Because there was no transport or storage required for the scions, it was not necessary to collect the scions early in the morning, covering them with wet rag or shading the grafted seedlings. All the leaves were removed from the scion and retaining few on the root stock before grafting was done.

The root stocks were perpendicularly severed at 20 - 30 cm above the ground while scion used were between 10 and 15 cm long. The root stock material did not have uniform thickness size and so was the scion, hence efforts was made to try to match the sizes and where it was not possible jointing was done careful to ensure at least one side of the root stock and scion cambium become complementary. The fitted scion and rootstock were tied tightly together using a translucent grafting tape. The tying was made tightly repeatedly in a coil fashion leaving no space in between and it covered at least 5 cm more on both the cut and joined areas of the root stock and scion. This was important in holding the parts firmly together, maintenance of humidity as well as protection against germs and water from contaminating the fresh wounds of the graft materials. Few leaves developing from the root stock were maintained while many were removed to reserve food and water for the developing scion.

Scions were collected from one plus trees selected using farmers' criteria. According to farmers, plus trees are the ones which have big crowns and big diameters which they say are the ones producing big and more fruits. Later assessment of fruit yield confirmed the farmers' criteria for plus tree selection (chapter 4 & 5) as relevant.

6.2.3.1 Whip and tongue method

After the 20 - 30 cm tall rootstock was prepared, a 4 to 6 cm long slanting cut was made at the top. A second vertical cut was made from mid-way along the slanting cut to form the tongue. The length of this cut was approximately 2 to 3 cm. On the scion a similar slanting and vertical cut was done at its bottom end to form a whip and tongue (Plate 6.3). The sizes of the cuts on the scion and root stock were made in such a way that they were roughly similar in shape and size in order to fit each other in the jointing process. To ensure all of these exercises were done accurately experienced and skilled grafting personnel were used. The scion and root stock were fitted together, carefully making sure the cambiums are perfectly complementary and thereafter tied with the grafting tape. A total of 40 seedlings (using 20 pairs of different scion sizes) were established using this method.

Plate 6. 3: Whip and Tongue grafting for *S. birrea* Kiegea, Morogoro

6.2.3.2 Top wedge method

The scion and root stock were selected in such a way that they were of closely equal diameter. Two slanting cuts were made on opposite sides of the base of the scion to make a wedge shaped end. From the top of the cross-sectionally severed root stock, a vertical cut of about 1.5 to 2 cm was made downward through its pith (Plate 6.4). Holding the rootstock with fingers the wedged scion was inserted through the vertical cut, ensuring the cambiums are perfectly matched before tying them together with a grafting tape.

Plate 6. 4: Top wedge grafting for *S. birrea in* Kiegea, Morogoro

6.2.4 Data collection

After grafting, monitoring was done after every 2 days for the first two weeks to ensure any development is not missed. After leafing, the grafting tape was not removed, but rather left on until a brown callus like structure was observed at the joining section showing that the joining has taken place. Grafting success was assessed by noting the date and number of leafing scions. Numbers of leaves were counted for each seedling while 3 leaves were randomly selected for measurement of petiole length and lamina width and length. The leaf of *Sclerocarya birrea* is compound and therefore top, middle and basal leaflets from 3 leaves from 10% of the plants were also measured for length and width.

6.2.5 Data analysis

Descriptive statistical analyses were done to obtain means and standard errors for various data obtained through measurements from the field. The results were used to generate bar charts and line graphs. Correlation analysis was done to understand the relationship between performance of grafting and grafting methods as well as specimen sizes. Two tailed independent student test was carried out to test the null hypothesis.

6.3 Results

6.3.1 Propagation by cutting and marcotting

These two experiments, propagation by cutting and marcoting, were not successful even after repetition. No root formation was observed in both cuttings and marcotting experiments. Out of the 640 cuttings, a few (11 cuttings) flushed out leaves after 5 to 15 days (figure 6.1) in the saw dust, rice husks and sand rooting media but eventually the leaves shed after 4 to 5 weeks. There was no leafing in the forest soil and mycorhiza soil rooting media.

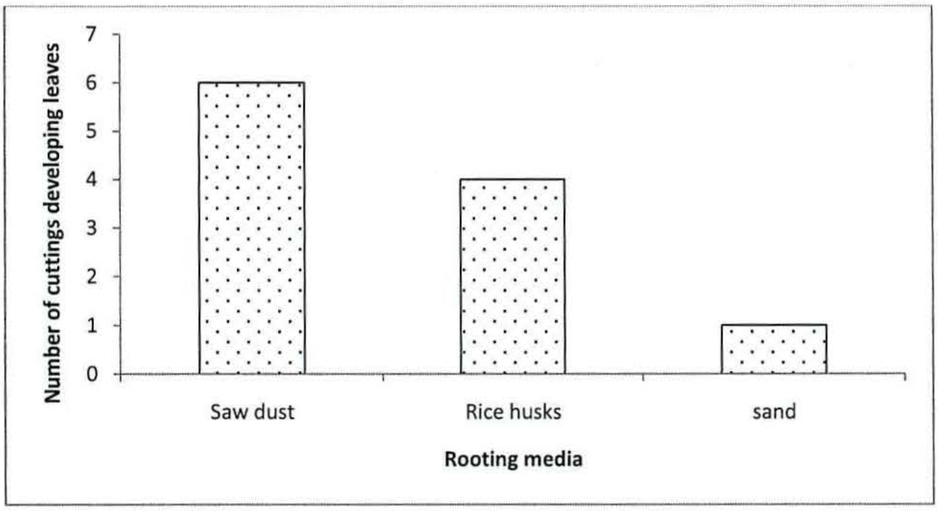

Figure 6. 1: Number of cuttings which formed leaves in the non-mist propagators under different rooting media

Plate 6. 5: Callus formation in an attempt to root *S. birrea* branches

For the marcotting experiment, most of them died probably due to infection while those few which survived formed callus (Plate 6.5). None of them succeeded in rooting. Similar results were found by Akinnifes *et al.* (pers comm.) in the early 2002 although their results were not yet published at the time of this study.

6.3.2 Grafting

Out of the 80 seedlings that were grafted, 79 of them produced leaves and eventually graft-take was successful. This is equivalent to 99% success, and it is a very high level of success which has never been achieved elsewhere for *Sclerocarya birrea* (Figure 6.2).

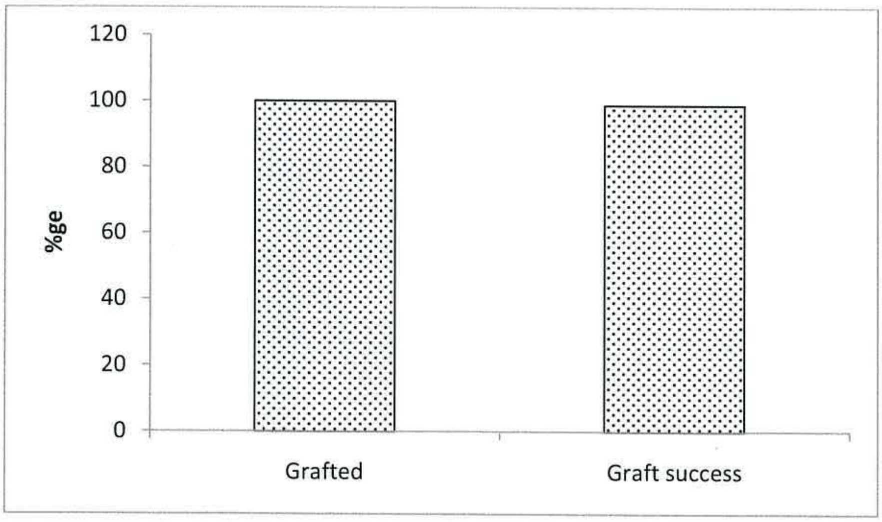

Figure 6. 2: Percentage of seedlings which had a successful graft-take using wild seedlings of *S. birrea* in Kiegea, Morogoro

After one week flushing started with 55% and 40% on seedlings grafted with the whip and tongue method using 5-10 mm and 11-20 mm scions respectively and 45% and 30% of the top wedge grafted seedlings with scion size 5-10 mm and 11-20 mm respectively. After two weeks 99% of them were flushing developing young leaves. The 1% which never flushed, eventually dying was on a whip and tongue graft size 11 – 20 mm (Figure 6.3).

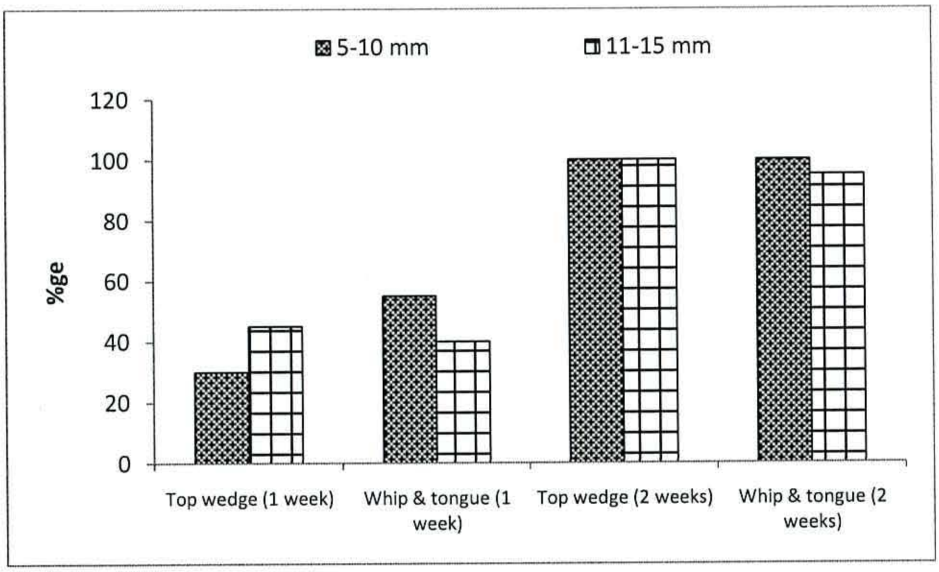

Figure 6. 3: Leafing of *S. birrea* wild seedlings using top wedge and whip & tongue grafting methods after one and two weeks in Kiegea, Morogoro

6.3.2.1 Height increment

Figure 6.4 shows growth in terms of height increment for the seedlings. The seedlings started to grow fast for the initial 3 weeks, and then slowed down and by the 12th week growth levelled off. The 14th week, which is approximately 3 months after grafting, was the period close to the onset of dry and cold season where also the whole population of *Sclerocarya birrea* was entering the leaf shedding period (Chapter 5). There were differences in terms of growth performance related to the grafting method and size of scion used. Smaller scions appeared to grow faster than bigger scions. Height increment for scions of size 11 – 20 mm after 14 weeks was 4.2 ± 0.25 cm and 3.7 ± 0.22 cm for whip and tongue and top wedge grafting respectively. For scion size 5 – 10 mm height increased by 4.6 ± 0.23 cm and 3.8 ± 0.26 cm in whip and tongue and top wedge grafting respectively after 14 weeks.

Two tailed independent student test analysis enabled us to reject the null hypothesis and hence accept the alternative hypothesis for the differences in performance of grafted *Sclerocarya birrea* seedlings using top wedge and whip and tongue methods. The null hypothesis stated that there is no difference in height increment for grafted seedlings among the two methods. The rejection of the hypothesis was significant at $p < 0.01$ ($t = -2.95$; $\alpha = 0.0043$; DF = 76). However when the same procedure was used to test the other null hypothesis "There is no difference in height growth of grafted seedlings between small and large sized scions" we were not able to reject the hypothesis because the p – value showed the differences in mean could have happened by chance. Results of general linear model analysis showed that it was the method rather than the size of scion used which was important in differences in height growth of the grafted seedlings ($p < 0.005$). This enabled the conclusion that whip and tongue grafted seedlings appeared to grow significantly faster than top wedge grafted seedlings but there was no significant differences in extent of growth when small size (5 – 10 cm diameter) or big size (11 - 20 mm diameter) scions were used.

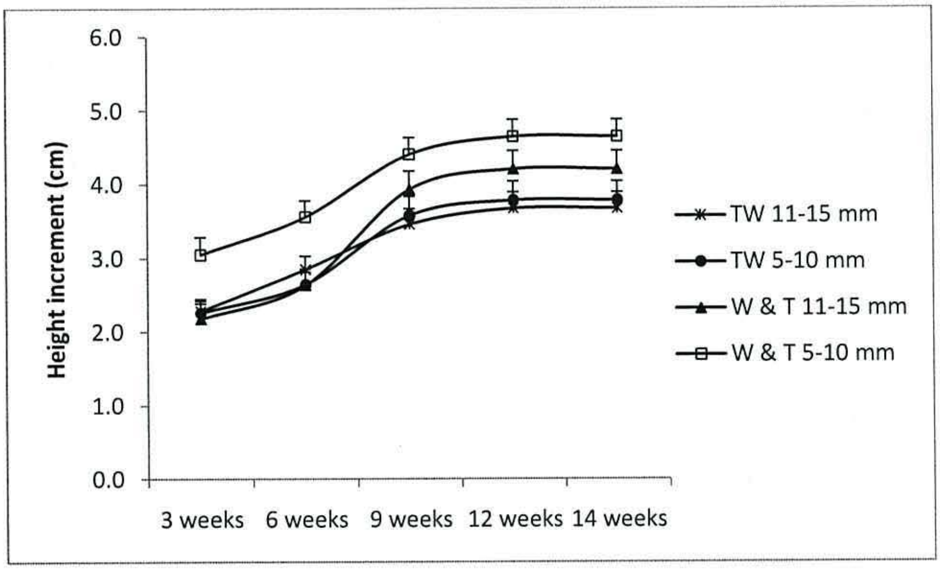

Figure 6. 4: Mean height increment in centimetres of *S. birrea* grafted wild seedlings during 14 weeks in Kiegea, Morogoro

6.3.2.2 Leafing

After one month no new leaves were produced by the grafted seedlings. Mean number of leaves was 11.00 ± 1.12 and 11.40 ± 1.00 for 11 – 20 mm and 5 – 10 mm sized scions respectively in top wedge grafting. For whip and tongue grafting the number of leaves was 9.60 ± 0.65 and 11.80 ± 1.02 for scions of size 11 – 20 mm and 5 – 10 mm respectively (Figure 6.5).

When the null hypothesis was tested using t-test, the only significant difference was found to exist in relation to the sizes of scion used under whip and tongue method. For the other scenario i.e. differences between methods used and the difference in scion sizes under top wedge methods; the differences in means observed could just be by chance. The significance level used to reject the null hypothesis which stated that "there is no difference in number of leaves developed between the two sizes of scions used in grafting by whip and tongue method" was $p < 0.1$ ($t = -1.76$; $\alpha = 0.089$; DF = 31). However using general linear model we managed to establish that the difference between the performances was due to methods rather than size itself ($p < 0.005$). This lead to conclusion that, statistically small sized scions produce more leaves than large sized scions only when whip and tongue method is used.

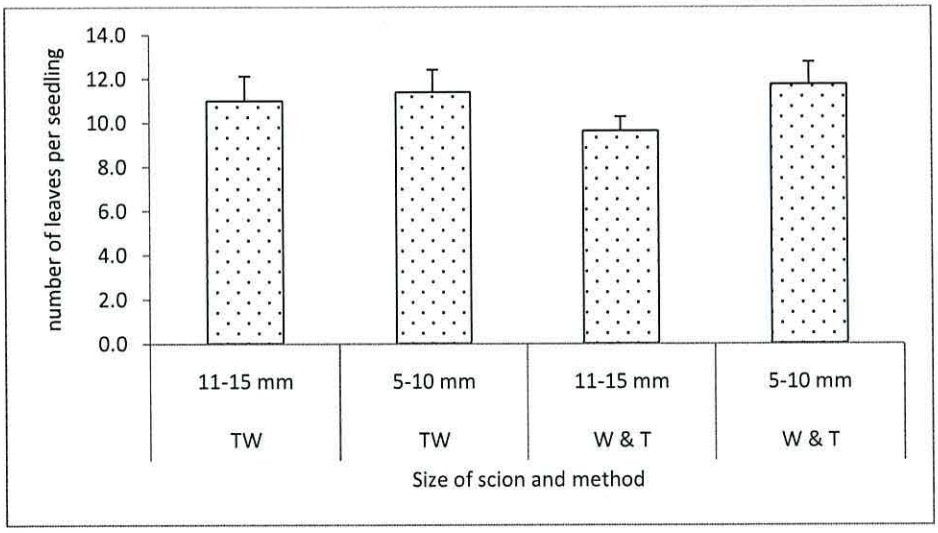

Figure 6. 5: Mean number and standard error of leaves per seedling for the different sizes of scion and methods of grafting (Top Wedge – TW; Whip and Tongue – W & T) for *S. birrea* in Kiegea, Morogoro

6.3.2.3 Size of leaves

Results for mean length of the leaf blades (excluding the length of stalk) of *Sclerocarya birrea* subspecies *caffra* are presented in figure 6.6. The mean length of leaf blades developing from the thicker scion seedlings (11 – 15 mm) was 9.38 ± 0.30 cm and 6.27 ± 0.61 cm for top wedge and whip and tongue grafting respectively. The mean leaf blade length of leaves developing from the thin scions (5 – 10 mm) was 11.00 ± 0.36 cm and 11.05 ± 1.15 cm for top wedge and whip and tongue grafting respectively. Using Student t-test the results revealed that there was no significant difference in lamina length between leaves developing from top wedge grafting and whip and tongue grafting. However there was a significant difference ($p > 0.01$) in lamina length between leaves developing from different sizes of scion used ($t = -2.84$; $\alpha = 0.012$; DF = 16). Using general linear model it was statitistically proved that the differences in length of leaf blades produced was due to the size of scion used and not the grafting method used. Statistically it can therefore be concluded that thin scions develop longer (11.03 ± 0.75 cm) leaves than thick scions (8.34 ± 0.58 cm) leaf blades.

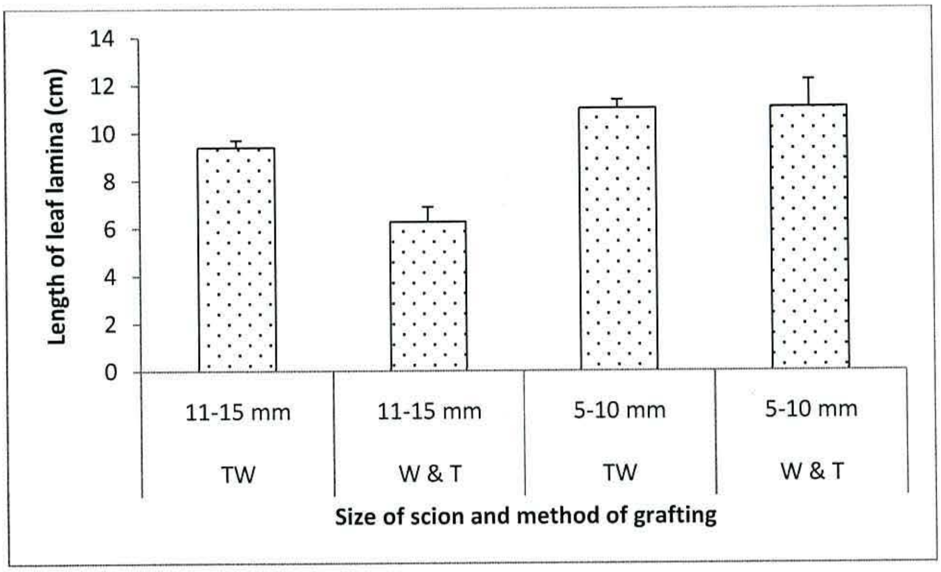

Figure 6. 6: Mean length of *S. birrea* leaf lamina measured from seedlings developing from 11 – 15 mm and 5 – 10 mm scions using top wedge (TW) and whip and tongue (W & T) grafting methods in Kiegea, Morogoro

6.3.2.4 Size of leaflets

Results to compare differences in leaflet sizes are shown in figure 6.7. The mean length of leaflets developed from 11 – 15 mm size scions was 3.67 ± 0.34 cm and 3.04 ± 0.03 cm for top wedge and whip and tongue grafting respectively while the mean length of leaves which developed from 5 -10 mm size scions was 3.69 ± 0.39 cm and 4.39 ± 0.22 cm for top wedge and whip and tongue grafting respectively. Using two tailed independent student test it was possible to accept the null hypothesis which states that there is no difference between the lengths of leaflets produced by seedlings grafted by top wedge and whip and tongue method. This is because the p-value was big suggesting that the different means obtained may largely be a result of chance or sampling error. However using the same test it was impossible to reject the null hypothesis that there is no difference in length of leaflet developing from small and big sized scions.

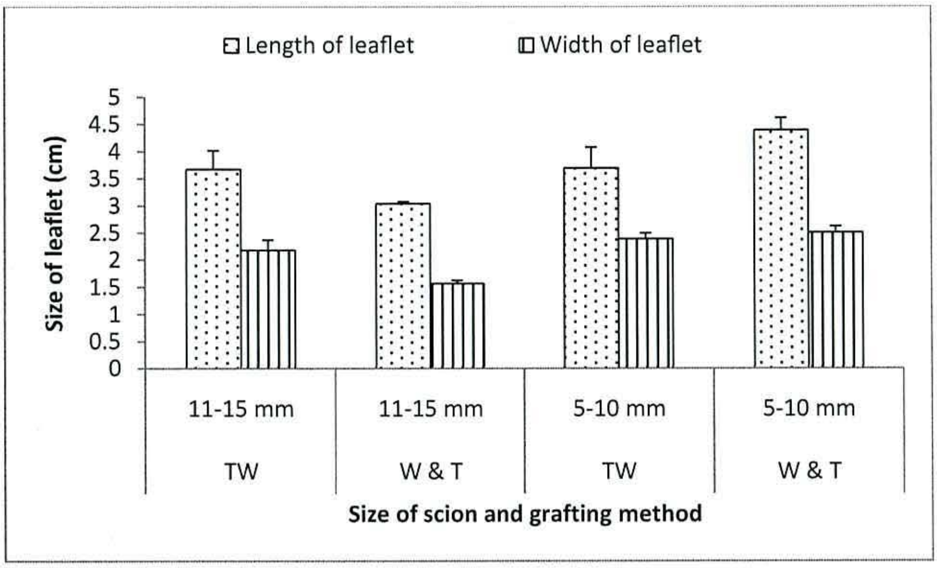

Figure 6. 7: Sizes of mature leaflets of *S. birrea* developed from top wedge (TG) and whip and tongue (W & T) methods using different sizes of scions in Kiegea, Morogoro

Small scions (5 – 10 mm thick) developed significantly longer (4.16 ± 0.22 cm) leaflets than big scions (11 – 20 mm thick) which developed significantly shorter (3.46 ± 0.24 cm) leaflets at $p < 0.1$ ($t = -2.12$; $\alpha = 0.051$; DF = 16). Using the general linear model it was statistically concluded that the influence on leaflet length development was due to size of scion rather than grafting method ($p < 0.1$). It can therefore be concluded that thinner scions tends to develop longer leaflets than thicker scions and that there is no significant difference in length of leaflets developed by either top wedge or whip and tongue grafting.

The mean width of leaflets developing from 11 – 15 mm size scions was 2.18 ± 0.19 cm and 1.57 ± 0.06 cm for top wedge and whip and tongue methods respectively while the mean width of leaves which developed from 5 -10 mm size scions was 2.39 ± 0.12 cm and 2.51 ± 0.11 cm for top wedge and whip and tongue methods respectively. As it was with length; the width of the leaflets which developed from the thin scions (5 – 10 mm thick) were significantly wider (with a mean of 2.47 ± 0.08 cm) than the ones which developed from the thicker scions (11 -20 mm thick) which had a mean width of 1.97 ±

0.16 cm at $p < 0.05$ ($t = -2.72$; $\alpha = 0.020$; DF = 16). There was no significant difference in leaflet width when the means of leaflets developed from the two methods were compared. General linear model proved that the differences in width of leaflets were due to size of scions rather than method used in grafting ($p < 0.01$). It was therefore concluded that the width of leaflets growing from thin scions was significantly bigger than the width of leaflets developing from thick scions.

6.3.2.5 Relationship between seedling parameters

Relationships between various parameters of leaves developed from the grafted seedlings are shown in Table 6.1. Pearson correlation analysis gave a strong positive coefficient of relationship between the length and width of leaflets ($r = 0.80$; $p < 0.001$).

Table 6. 1: Pearson correlation values between various seedling leaf parameters

	Stalk length	Leaf Blade	No. of leaflets	Length of leaflet
Length of leaf blade	0.85 (0.001)			
No. of leaflets	-0.09 (0.735)	0.18 (0.464)		
Length of leaflet	0.77 (0.001)	0.53 (0.023)	-0.31 (0.213)	
Width of leaflet	0.82 (0.001)	0.70 (0.001)	-0.143 (0.572)	0.800 (001)

* *Figures in bracket = p-value*

Regression analysis gave the equation $W = 0.415 + 0.474L$ where W stands for width of leaflet and L stands for length of leaflet with predictability (R^2) = 56.66 % at $p < 0.001$. There was also a relationship between the length of the leaf blade and width and length of leaflets. The relationship between length of leaf blade with leaflet length gave a Pearson (r) value of 0.53 at $p < 0.05$ while the relationship between length of leaf blade and leaflet width gave a Pearson (r) value of 0.70 at $p < 0.001$. The length of leaf stalk had a strong positive correlation with leaf blade ($r = 0.85$; $p < 0.001$), length of leaflet ($r = 0.77$; $p < 0.001$) and width of leaflet ($r = 0.82$; $p < 0.001$). The number of leaflets in a leaf blade showed weak negative relationship with petiole length, length of leaflets and width of leaflets and the relationships were not significant. According to Cohen (1988) interpretation, *r* values between 0.5 and 1.0 indicate a strong relationship; therefore both the width and length of leaflets of *Sclerocarya birrea* subspecies *caffra* strongly correlate with leaf blade and stalk length. It therefore means that probably a long leaf provide enough space in between the petioles for them to grow.

6.3.2.6 Flowering and fruiting

No flowering and hence fruiting was observed on the first season which was one year after grafting. However in the second year (season), flowering was observed from 5 plants of which two of them produced fruits (Plate 6.7). The plants which produced fruits were both grafted using whip and tongue method, small scions but flowering occurred also on top wedged plants. At this point only 18 out of 79 plants were surviving after a fire incident which occurred during the dry season in the second year. Flowering was observed at different days during December 2010 and the two plants which flowered early were the ones which produced fruits. One plant produced 7 fruits while the other produced 3 fruits.

Plate 6. 6: The plant in December 2010, January and February 2011

Plate 6. 7: Fruiting of 2 years old grafted *Sclerocarya birrea* plants

6.4 Discussion

6.4.1 Vegetative propagation by cuttings and marcoting

None of the cuttings or marcots produced roots in this study. Even after repeating the cutting experiments in different seasons and using different ages of cuttings i.e. old and juvenile cuttings results remained negative. Some few cuttings produced leaves and after continued monitoring the only development observed at the end for both cuttings and marcots were calluses. Some of the previous work has reported that these methods produce successful results for *Sclerocarya birrea* while recent studies have shown results have similar to the current study. Holtzhausen (1990) reported some level of successful rooting of *S. birrea* cuttings but Akinnifesi *et al.* (2008, *pers. comm.*) did a rooting experiment for the same species and observed no rooting. Even when they applied hormones the cuttings ended up at the stage of callusing. However their results were not published and therefore not available before our study.

The main idea behind propagation by cuttings is only to induce adventitious root formation because a potential shoot system (the bud) is already present. This process is highly dependent on genetic and physiological capacity of particular plants for its success. However despite many years of intensive research, the fundamental biology of what triggers adventitious root formation remains largely unknown (Hartmann *et al.*, 1997). Basically the process is dependent upon the ability of plant cell differentiation but the tissues involved can vary widely depending on the kind of plant and propagation technique used (Altamura *et al.*, 1991). So although it was reported that, most of the African woodland species have the potential to develop roots from cuttings (Leakey, 1990), the process is not straight forward because of different species, genetical variation and propagation techniques which can be used. The existence of contradictory findings on use and performance of cutting for propagation of *S. birrea* by various researchers (Shone, 1979; Holtzhausen *et al.*, 1980; Holtzhausen, 1990; Lars and Marina, 2000; Hall *et al.*, 2002, Maruzane *et al.*, 2002; Shackleton *et al.*, 2002; Mng'omba *et al.*, 2008, ICRAF, undated) may be one of the evidence for this theory.

For *Sclerocarya birrea* more anatomical and biotechnological work will need to be done to establish the nature of its cell differentiation and specific requirements needed for rooting of cuttings. It is reported that adventitious root formation for woody plants usually originate from living parenchyma cells, in young secondary phloem but vascular rays, cambium, phloem, callus or lenticels can also develop the roots (Lovell and White, 1986; Harbage *et al.,* 1994). For some plants which are normally referred to as *difficult-to-root* plants (Ford *et al.,* 2001), the process is indirect going through indirect cell divisions including callus formation during an interim period before cell divide perfectly in an organised pattern capable to initiate rooting (Hartmann *et al.,* 1997, Ford *et al.,* 2001). Since the results from the current study, as well as those found by Akinnifesi (2008, pers. comm.) and his team of experts in the 1990s, ended up forming calluses only; it suggest that *Sclerocarya birrea* may be among the *difficult-to-root* plants. There are other studies which have also associated callus formation with *difficult-to-root* species (Hiller, 1951; Cameron and Thomson, 1969; Davis *et al.,* 1982). More work needs to be done to investigate what is needed to move from the interim callus period to proper pattern of cell differentiation for adventitious root formation in *Sclerocarya birrea*. It is very important to investigate the specific details of procedures applied by the past scientists who have reported success of rooting from cuttings for this species. However with similar aims like the current study of devising an affordable approach practical to rural African farmers, these findings and the complexity that may be involved in difficult-to-root plants indicates use of cuttings may not be feasible. But, for large scale commercial farming of *Sclerocarya birrea*, break through findings for rooting of cuttings may still be very worthwhile.

Air layering has also been used as a technique to propagate *difficult-to-root* species (Turkey, 1964; Rom and Carlson, 1987; Hartmann *et al.,* 1997). Although uneconomical and too laborious this technique is still preferred to use in propagation of *difficult-to-root* species (Hartmann *et al.,* 1997). Unlike cuttings, the physical attachment to the stem of the plant during rooting allows for continued supply of water, minerals, carbohydrates and hormones through the intact xylem and phloem to the rooting area (Riv and Reuveni, 1984) while leaching of nutrients and metabolites associated with mist systems is also avoided (Hartmann *et al.,* 1997). Callus formation results have similar implications as in cuttings. It means that specific techniques needs to be investigated and developed to induce rooting after callusing for *Sclerocarya birrea*.

6.4.2 Vegetative propagation by grafting

Leafing process was observed from the flushing stage where the leaves started to appear and had red-brown-green coloration. Coloration of leaves is associated with dimorphism to deal with herbivory (Hansen *et al.*, 2004; Ghazoul and Sheil, 2010). Grafting was 99% successful in this study. For *Sclerocarya birrea* this is one of the highest success rates reported so far and the first one which has used wild seedlings. Few studies have reported percentage of success on grafting of *Sclerocarya birrea* (Hall *et al.*, 2002). In a study where conditions were highly controlled, Holtzhausen (1990) reported 80 % to 98 % success while Akinnifesi *et al.*, (2005) reports grafting success of 52 – 80 % under nursery conditions. It is also reported that graft-take was low as 10% (Jaenicke *et al.*, 2001) and low survival and growth were reported on farmers' fields (Mhango & Akinnifesi, 2001) in domestication attempts conducted in the early 1990s by ICRAF.

It is important to note here the modification of the techniques resulting into the unique procedure used which employed the simplest and affordable methods to poor farmers. Grafting, depending on place of application, procedure, and materials used can be expensive to surpass micro-propagation (Hartmann *et al.*, 1997). Unlike previous studies, wild seedlings naturally regenerated from seeds were used and avoided covering the grafted seedlings with plastic bags to maintain high humidity; one of the steps involved in grafting but still managed to achieve a very high grafting success. Use of plastic bags could attract destruction by enthusiastic passer-bys or playing children and could also result in conflict between farmers if swallowed by grazing livestock. The key to success was the skills and experience of the grafting personnel. This can be proved by the fact that although farmers (through a trial participatory experiment) managed to get some results (25% success – 3 out of 12 seedlings) the difference was the skills and experience because they followed similar procedures, only that they had done it for the first time. With more time and practice the technique can be successfully used by farmers.

It is for the first time that participatory vegetative propagation experiments for *Sclerocarya birrea* have been done and more interesting is the high level of success. The procedure is cheap, easy to follow and can be disseminated easily as wide as possible by other scientists, outreach experts as well as through farmer to farmer exchange of knowledge.

6.4.2.1 Height increment

Whip and tongue grafting showed significantly more growth in terms of height increment than top wedge grafting. Whip and tongue grafting revealed superior performance in another study on *Vitex payos* conducted by Kimondo (2010). There is no clear explanation for the differences although there is a possibility that in whip and tongue there is relatively better close contact between scion and root stock which facilitates faster regeneration. Mencuccini *et al.* (2007) points out that growth performance of seedlings from different techniques is determined by the speed of graft take and recovery. Based on our findings whip and tongue method produce better performance but clear cut details of the reasons behind is beyond the scope of this study.

The size of scion used did not show any significant difference in height growth. In the study by Kimondo (2010) they used various sizes of scion and were not able to establish the performance of seedlings in relation to size. He recommends standardisation of sizes of scion used, which we did in our study, for evaluation of growth performance. Different sizes of scion have different nutritional status which remains in the seedling for a considerable period after grafting (Sweet, 1973). However this influence of scion size was not reflected in early growth of seedlings in terms of height for *Sclerocarya birrea*. But as will be discussed later the sizes differences were reflected in growth of leaves.

6.4.2.2 Leafing and leaf development

Number of leaves developed by seedlings was higher in the seedlings grafted using whip and tongue method and especially better when using small sized scions. The first important sign of success of grafting is leaf flushing although union of cambium is the most important and confirmatory indicator of graft compatibility and success (Hartmann *et al.,* 1997). Flushing started as soon as after a week and within two weeks maximum success (99%) had been achieved. Leaf development is very important in propagation for it is the site for manufacture of food for development of the seedlings. Seedlings with more developed leaves are normally able to manufacture more food and therefore grow faster (Kitajima *et al.,* 2000). However it should be noted that leaves are also sites of plant water loss although the surrounding environment will play a big role in water balance. Since the grafting was done during the rain season and indeed on wild seedlings with well developed root system, water loss could be easily replaced from the environment. Therefore the amount of leaves developed by grafted *Sclerocarya birrea* wild seedlings could positively influence the rate of growth of the developing new plant.

The differences in size of leaflet lamina were significant between sizes of scions used. Small sized scion (5 – 10 mm in width) developed bigger sized leaflet than bigger sized scions (11 – 20 mm in width). Other results for leaf development include number of leaflets per leaf and size of leaflets (morphology). There was a strong correlation (r = 0.8) between length and width of leaflet as well as between leaf lamina and sizes and number of leaflets. Small sized scions produced bigger sized and more leaflets than thick scions. Therefore in terms of leaf development the difference was more due to size of scion than method of grafting used as it was the case for growth of the stem.

The fact that small size scions showed better leaf machinery development may be associated with its more active growth properties. It is more likely that the small scions are much younger, still growing and developing compared to the bigger sized scions. Meristematic cell division activities are higher on the smaller/younger scions and hence capable of developing the buds into leaves faster or quickly than those in more matured and more lignified bigger scions (Greenwood *et al* 1988; Mencuccini *et al.,* 2007, Amri, 2010). It is reported that it is difficult and expensive to propagate old and hard materials for tropical trees (Amri, 2009). Since the findings of this study showed significant difference in term of growth between the two methods and materials; logically it implies that using small scions and whip and tongue grafting will significantly improve growth and development of grafted seedlings for *Sclerocarya birrea.*

Plate 6. 8: Grafted *S. birrea* seedlings at different phenological stages (pictures taken on the same day)

It may be useful to monitor the differences in development to the level of reproduction to see if this initial development has an influence in more reduction of juvenility of *Sclerocarya birrea*. Comparison of growth among seedlings of *Sclerocarya birrea* has been reported to be significant by Chirwa *et al.* (2007) but the difference is that they used germinated seedlings and were comparing provenances and not methods unlike the current study. They attributed the differences in performance with genetic variation but suggest more studies to confirm this. The results from the current study cannot conclude anything related to genetic variation because scions were collected from one parent, their suggestion thus remain valid and still a subject for further assessments. While a height growth of 3 - 4 cm in 14 months was recorded; Chirwa *et al.* (2007) reports 1 – 2.2 m growth in three years. It is difficult to compare these two results because of the duration, location, method and stock used. Chances are that after the initial development growth may accelerate due to much more developed photosynthetic machinery or the amount of rainfall will never be the same year after year. After all seedlings in this study were growing in a wild condition with competition and fire attacks likely to influence the plants where as for the case of the study by Chirwa *et al.* (2007) the plants were under a much more controlled nursery care.

The results of the present study of fruiting of at least two plants confirmed that grafting of wild seedlings of *Sclerocarya birrea* is a successful procedure. Although only two plants produced fruits (2 out of 79 plants) two years after grafting, flowering was observed in at least five plants. Of the 79 plants which were grafted successfully 61 died in the second year due to a fire incident and may therefore have influenced the results of number of plants which flowered and fruited. Currently the remaining plants have been fenced and the ground around them has been cleared to improve their protection (Plate 6.9). Some of the flowers were aborted probably due to unsuccessful pollination. Irregular flowering and therefore fruiting of young *Sclerocarya birrea* plants have been observed by Taylor and Kwerepe (1995); Taylor *et al.* (1996) and Chirwa *et al.* (2007). They reported failure to flower by some plants while other plants flowered in the second year but did not flower the next year.

Plate 6. 9: Clearing and accumulation of soil around seedlings for fire protection and maximizing rainwater retention

The number of fruits produced was small (max. 7 fruits/plant) probably because of less pollination intensity and few numbers of branches on the grafted plants. Kimondo (2010) reported production of up to 30 fruits on a grafted Vitex payos plant in the second year in Kenya.

It should therefore mean that for best results the best option is to use small sized scions and whip and tongue grafting because both of them showed more growth although in different parts assessed. It means a combination of both maximises success of grafting of *Sclerocarya birrea*. The methods used in this study involve slight modification of the conventional grafting techniques to make them practically and economically affordable by small scale farmers. Hormones for growth enhancement or plastic covers for moisture retention were not used and yet a very high grafting success was recorded. Low cost effective propagation techniques for woodland species in Africa are lacking hence slowing down domestication campaigns (Akinnifesi *et al.*, 2006). These results contribute to solving this problem and present a chance for accelerated domestication and utilisation of *Sclerocarya birrea*.

CHAPTER SEVEN: GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATION

7.1 General Discussion

Although *Sclerocarya birrea* is a very useful resource, found in many parts of Africa, and Tanzania being the centre of its diversity (Kadu *et al.*, 2006; Chirwa & Akinnifesi, 2007, Teklehaimanot, 2008); little has been done to maximize benefits to farmers from the vast potentials held by the tree. Despite the uniqueness of the population, majority of research on the species has been done outside Tanzania making subspecies *multifoliolata* hugely under-researched compared to *birrea* and *caffra*. *Sclerocarya birrea* emerged first in the list of priority species for development and domestication in Tanzania (Teklehaimanot, 2005). Given that material for field study is available in Tanzania, the opportunity was taken to simultaneously assess and compare the three subspecies of *Sclerocarya birrea* for the first time. The broader aim was to generate knowledge which can assist improving the management and utilization of marula trees in Tanzania as well as in other countries.

This study was done to generate information useful in comparing the three subspecies of marula as well as for improved management and domestication of the species. The first activity was to assemble and synthesize the existing knowledge in relation to traditional knowledge on management and use of the species, population status and distribution, genetic variation, regeneration, associated soil properties, associated species, phenology, fruit production, fruit properties and vegetative propagation. There was adequate information on *Sclerocarya birrea* but mostly from areas outside Tanzania focusing on subspecies *birrea* and *cafra*, each study covering few aspects and in most cases a result of surveys including several or groups of vegetation. Therefore the rest of the research activities aimed at filling the gap of information in order to help in developing strategies and programs for effective management and conservation of the species as well as sustainable utilization of its resources in Tanzania.

The second activity was an assessment of traditional knowledge and local constraints important for development of strategies for improved management and use of *Sclerocarya birrea*. Although information related to *Sclerocarya birrea* exists, especially from locations outside Tanzania; it was realised that traditional knowledge varies from one place to another for various complex reasons (Berkes *et al.,* 2000). Global changes are said to have imparted a significant change on less dominant cultures of the world and consequently the ways of life of people in rural areas (Berry, 2008). This in turn erodes conservation and perpetuation of traditional knowledge on uses of resources. As a result, the current generation especially in Africa knows little about traditional knowledge compared to past generations. The knowledge about uses of *Sclerocarya birrea* for various purposes is old and current knowledge maybe different. It was therefore useful to understand the current local knowledge associated with the three subspecies in order to build a foundation for improved management plans. For impacts to be substantially realised improved management plans for exploitation of forest resources in developing countries need to merge existing local knowledge with external or western knowledge (Ostrom, 2009 a&b).

A third activity was a population study which involved assessment of population status, distribution, associated soils, associated species and mode of regeneration. Knowledge of a species population provides a picture on future prospects of the resource and how possible it can be managed in a sustainable way (Mwang'ingo *et al.,* 2002; Akinnifesi *et al.,* 2008). While such studies enable us to understand the reproductive biology of a species they also help to identify important materials for genetic improvement and in situ conservation (Mwang'ingo *et al.,* 2002).

The fourth activity was assessment of the species phenology, fruit yield and properties. Phenology is among the less studied aspects of *Sclerocarya birrea* throughout its range despite its importance in management planning. Leafing and shedding information is important not only in understanding the individual species but also in planning and managing understory or associated crops especially in agroforestry systems (Huxley, 1996). Similarly, knowledge on reproductive phenology and pollination biology are basic elements that should be considered in the management and exploitation of plant species that offer non-timber products (Salinas-Peba and Parra-Tabla, 2007, Nayak and Davidar, 2010). On the other hand, knowledge of fruit physical properties and yield is imperative for trees with commercial domestication prospects like *Sclerocarya birrea.*

A fifth activity was to develop an affordable and locally practical, easy to adopt propagation method which suits farmers' socio-economic and environmental conditions.

Vegetative propagation is considered superior in reducing maturity longevity and multiplying desirable plant traits but the challenge is that the available methods are expensive and mostly nursery based (Amri, 2010). Moreover in the existing literature on propagation of *Sclerocarya birrea* it has been reported differently or rather opposing results in terms of feasibility and success (Shone, 1979; Holtzhausen *et al.,* 1980; Lars and Marina, 2000; Hall *et al.,* 2002, Maruzane *et al.,* 2002; Shackleton *et al.,* 2002; Akinnifesi; 2004; 2008; Mng'omba *et al*, 2008 and Kimondo, 2010; ICRAF, online). According to Akinnifesi *et al.* (2006), lack of knowledge on reliable propagation methods has slowed down domestication of many IFTs. For instance while some researchers are reporting *Sclerocarya birrea* to successfully propagate from cuttings, others claims failure of rooting from cuttings. Where success is reported, the techniques used involve materials and methods which are relatively technical and too costly to handle by poor farmers. Since in the end the farmers are the ones with the responsibility of domestication, development of a simple and cheap vegetative propagation technology will make a huge contribution (Amri, 2010).

7.2 Hypotheses and ideas

7.2.1 Traditional Knowledge

Results showed that *Sclerocarya birrea* ranks high as a tree important for livelihood in Tanzania. It is important to note that marula priority/rank in the study villages varied while also it did not rank 1st as it was in the work by Teklehaimanot (2004); showing that priority ranking of species is village/location specific. The variation in ranking of tree species for priority has also been observed by Okia (2010) in his study on *Balanites egyptiaca* in Uganda. The importance of a species to farmers is, among other things, subject to its abundance, usage, local knowledge and presence of alternative species. In Holili and Malinzanga, *Sclerocarya* ranked higher than Mango which is a popular and important exotic fruit (Jama, 2008). This indicates that indigenous fruit trees (IFTs) are gaining recognition. Results may change if this prioritisation is repeated in other villages or using a different group of farmers due to variation of perceptions and local knowledge but for IFTs promoters the position of marula over Mango in the two villages is encouraging.

The way farmers manage land and crops in relation to prospects of continued and improved integration of *Sclerocarya birrea* in agroforestry systems was promising in all sites. Food crops and tree species have been integrated in land that was acquired mainly through inheritance, hiring, purchase and forest clearance or encroachment. With the exception of land hiring, which was land use practiced by few people, other means of land ownership allow farmers to plant/retain trees for those who are interested to do so. This is because of the security of tenure available in traditionally owned lands, which allows and encourage long term investment such as tree planting (Sjaastad and Bromley, 1997; Place, 2008). The existing land use systems and practices as well as the experience of farmers in integrating marula with food crops provide a promising foundation for improved domestication of the species.

Although the uses of marula mentioned by farmers are important, it was evident that the most important asset of the species, which is the fruit, (Akinnifesi et al., 2008) is underutilized in Tanzania. While various processed products such as beverages and cosmetics are being exported from especially South Africa and Namibia to world markets, such opportunities remain untapped in Tanzania. At the local market the fruits were not traded in all the study sites. Sales of these fruits are reported in Teklehaimanot (2008) to be done in some areas in central Tanzania. Wider surveys could therefore come up with a different picture although intensive trade and processing is highly unlikely to be found in Tanzania because if it existed it could easily be noticed in regional local markets.

Local knowledge on various techniques of utilization of resources contributes in defining the status of exploitation by the respective societies. Variation in traditional knowledge is multifaceted (Steele and Shackleton, 2010) and needs to be integrated to macro level policy systems if real impacts are to be realized (Ostrom, 2009a). From this study, we cannot tell if the fruits were more utilized in the past than they are now in Tanzania, but the need for alternative crops to cope with hunger and poverty places *Sclerocarya* at the top of the list of trees important for promotion and eventual domestication and utilization. To begin with, farmers in Tanzania can copy local processing and trading from other countries. Local farmers in southern and western African countries use the fruits to make and trade refreshment beverages, cooking oil and cosmetics (DFID, 2003; Nghitoolwa *et al.*, 2003; Sidibe, pers. Comm.). On the other hand, communities in Tanzania use grains such as maize and sorghum to make similar refreshments causing hunger crisis every year. The government as well as the community continues to struggle to get a solution for stopping the use of food crops for making refreshments. Therefore promoting the use of marula fruits as an alternative material for making the beverages will not only contribute in saving the grain reserves but will also lay a foundation for future large-scale processing and trade on marula products in Tanzania.

This is the first study on marula to report that it is used for timber. The use of marula for timber was reported on the less studied subspecies *multifoliolata*, hence justifying the need for more assessments covering and comparing the three subspecies. Subspecies *multifoliolata* scored 4/10 as a timber tree and 3/10 as a fuelwood tree indicating that it is regarded as among the useful species for its wood at least in the study village of Malinzanga. It may therefore be important to compare the wood strength and calorific properties of the three subspecies in Tanzania to understand if Subspecies *multifoliolata* possess more suitable qualities for timber uses compared to subspecies *caffra* and *birrea*. Wood from subspecies *caffra* and *birrea* from other countries have been studied before (Hall *et al.,* 2002)

In all three subspecies crown and trunk diameter were the most important criteria for selection of superior trees. Farmers relate these attributes to provision of better shade, timber as well as yielding more fruits. Farmers' selection criteria for superior trees were thus influenced by the types of products and services they intend to get from the trees. Other criteria used for *Sclerocarya birrea* are fruit size, quantity and taste. For breeding and domestication purpose these factors needs to be taken in consideration. It will be important to test the validity of these criteria because the sizes of the crown and trunk relates not only to genetic properties but also age of the individual trees (O'Brien *et al.,* 1995). Since trees on farmers' lands are of various age and different crown sizes it is not known whether the big ones were intentionally selected and retained since they were young.

Despite ranking marula as a priority species and having the knowledge on features of superior trees, few farmers domesticate the trees on their farms especially in Holili and Malinzanga villages. Potential barriers to domestication of *Sclerocarya birrea* which were put forward include poor understanding of legal institutions, wildlife conflicts, ignorance of the tree values and its market as well as plentiful of the trees in the wild. Many farmers think that all trees belong to the government and for one to harvest will require applying for a user-right permit due to misunderstanding of the 2002 Forest Act (66). Although this is largely a misconception of the enactment of the protected species and special habitats act, it significantly affects tree planting and management in agroforestry systems. Also to keep out crop raiders especially monkeys, farmers avoid trees which are regarded as habitat and corridor for the animals on their farms. Wildlife conflict is regarded as a serious problem to farmers and conservationist in Tanzania with no clear-cut and effective solution until now (Sillero-Zubiri and Switzer, 2001). As it is in many regions, indigenous fruit trees (IFTs) values are neglected in preference for exotic varieties (Jama *et al.,* 2008). Also lack of trees on farms is partly because some farmers do not find it necessary or important to own the trees on their farms since they can collect products like fruits or medicine from wild resources, although this practice is becoming unsustainable (Akinnifesi *et al.,* 2008).

Creating and improving markets would be a big driver for greater investments by farmers and the private sector in the production and commercialization of marula. Without an expanded or a new market, the incentives to domesticate intensively for self-use are not sufficient (Leakey and Simons, 1998). Markets should include local, regional and global markets. For instance, Boersma (2005) observed growing demand for mangoes within urban populations, thus opening up new marketing opportunities for smallholder farmers. The mango marketing chain in Kenya is fairly well developed (Mungai et al., 2000, Jama et al., 2008) and could provide insights on how to do the same for marula. For marula, developing market links with the beverage industry will be essential to improve the use of this species, although starting with promotion of village level market creation and development is key to success.

7.2.2 Population status, regeneration and associated species

Differences in abundance were observed between subspecies, environment and sex of the tree. Since the survey used one village per subspecies we should not rule out different result should more sites per subspecies be included in another assessment. Therefore although subspecies *caffra* was the most abundant, the conditions and local perceptions towards the subspecies in the studied village could have influenced the results. Similar studies should therefore consider modification of assessment approaches to include at least three sites per subspecies if time and resources are not limiting.

On farm populations for one subspecies (*caffra*) was more abundant than its wild population. Normally we would expect on farm populations to be less dense than wild population due to creation of more space for agriculture (Leakey, 2005; Gouwakinnou *et al.*, 2009). Therefore the status of subspecies *caffra* on farm population indicates that, farming does not always have to involve large scale removal of trees and that domestication of the marula as an agroforestry component is feasible. However further assessments on its tree-crop interaction is important to obtain information on types of intercrops, optimum spacing, influence on yield, etc.

It has been reported that, because of many years of usage of the fruit of marula trees, females are more than males especially on farm populations as a result of farmers' selection bias. (Botelle 2002; McHardy 2002; Shackleton et al. 2003; Ngiitolwa *et al.,* 2003; Gouwakinnou *et al.,* 2009). In this study the situation was opposite, there were more males. While lack of intensive use of the fruits, hence less selection bias; in Tanzania may come as a quick explanation for the difference it is also important to consider other factors such as physiological mechanisms. Some studies have suggested that for the resulting seed embryo to be female more pollens are needed to fertilize the ovaries (Stehlik *et al.,* 2006; 2007; 2008). The more the concentration of pollen deposited onto a female flower the more likely the resulting offspring will be a female. For commercial domestication purposes where the female trees are a priority, vegetative propagation techniques will help to produce the desired. If this is to take place plans to allow natural gender balancing of the species must be put in place. This could be achieved by for instance setting aside *in-situ* conservation stands in all villages which will participate in improved domestication of marula.

All the populations were observed to be randomly distributed with $\boldsymbol{R}$ values close to 1.0, meaning that the observed distribution (r_o) was close to the expected distribution (r_e) as $\boldsymbol{R}$ is the ratio between the two ($\boldsymbol{R} = r_o/r_e$). Given that the areas were different in size hence differences in density, the randomness is due to the values between pair trees making up a significant portion of the total population (Cottam and Curtis, 1956). Since both wild and on farm populations showed random distribution it indicates that human activities have limited influence on the species distribution. Distribution of certain species tends to be aggregated in village settlements and developed farmlands because they are selectively retained or planted for their usefulness in livelihood of the farmers (Kimondo, 2010). It means that improved domestication of marula is likely to change the distribution of its population from normal to aggregate.

Tree height, diameter and crown size was different between the subspecies, environment and sex. The expectation was for on farm trees to be bigger due to farmers' selection bias, management and care as well as reduced competition (Shackleton et al, 2003; McHardy, 2003; Leakey, 2005; Gouwakinnou *et al.,* 2009), but in one of the sites (Kiegea) the findings were opposite. Instead tree size parameters showing a relationship of variation by environment, they related to abundance of the populations. Results showed that trees in sites with less abundance were taller with bigger stems and crowns. The relationship between the sizes of trees and abundance of the populations regardless of subspecies and environment suggested that intraspecific competitions affects the sizes of marula trees although this study does not have sufficient data to conclude this. Duchesneau *et al.*, (2001) suggest intraspecific competition to be an important factor determining sizes of trees. For domestication purposes it will be useful to develop and implement appropriate spacing of the species because size of marula trees is important for results showed high yield of fruits to relate to big trees.

Overall subspecies *multifoliolata* had the biggest trees and across all the subspecies and environments male trees were bigger than female trees. Variation in sizes of trees may also be influenced by factors such as genetic properties and environmental properties such as rainfall, soils and fire (Mwang'ingo, 2002) and these could also explain the differences between the subspecies. Fire, depending on frequency and intensity, tends to inhibit growth of woodland trees (Chidumayo, 1988; Zolho, 2005). Subspecies *caffra* populations which were burning every season had the smallest trees. There is no a previous study which has assessed the differences in size between the subspecies and sex of *Sclerocarya* trees. However it is known that female plants spend a lot of food reserves for reproduction while for male trees such reserves are available for growth (Correia & Barradas, 2000; Wheelwright & Logan, 2004; Guangxiu, 2009; Varga & Kytöviita, 2010). This may explain the differences although long term and wider coverage studies particular to *S, birrea* are necessary to make a concrete conclusion. Wider coverage in terms of more study populations per subspecies taking into consideration other factors such as variation in rainfall, soil and management will also strengthen observed differences in sizes between the subspecies.

Regardless of sex and with the exception of subsp. *multifoliolata*, branching height for on farm trees was lower. It appears that farmers do not prune lower branches probably for the tree to provide good shade. But presence of more fire incidents and competition for light, wild populations tend to grow taller and lower branches may be removed by fires (Osada *et al.,* 2004; Ribeiro *et al.,* 2008). Low-level branches enable the crown to cast shadow in a wider space. The influence of marula shade and litter on intercrops and soil micro-organisms need to be assessed. However farmers in the site where subsp. *multifoliolata* is found are close to Ruaha National Park and tend to dislike trees on farms for they regard them as a habitat and corridor for monkeys who raid their crops. They therefore tend to prune and remove the *Sclerocarya* trees on their farms to destruct movement of monkeys from tree to tree and therefore probably the observed high branching height.

The soil classes; clay loam, sandy loam and loamy clay; observed across all the populations have been mentioned in other reports on soils found in *Sclerocarya birrea* habitats (Hall *et al.,* 2002). Our results shows low levels of organic matter content and exchangeable bases; and total nitrogen (N) ranging from 0.1 - 0.14% and are in line with other reports (Werger and Coetzee, 1978, Shackleton and Scholes, 2000, Hall *et al.,* 2002). There was no observed influence of *Sclerocarya birrea* trees on soil properties and in future sampling of soils away from the trees should be taken from a much distant points (15 – 20 m).

As detailed in the literature (Helm and Witowski, 2008; Akinnifessi *et al.,* 2008; Gouwakinnou *et al.,* 2009), little is documented on the regeneration ecology of *Sclerocarya birrea* in its natural habitat The present study found that regeneration from stem coppicing and root sprouting was more dominant that that from seeds. This suggestion is based on the assessment of the surviving young plants and should not imply less germination potential of marula seeds. This is because under mother trees several seeds were observed during the rain seasons but most did not survive to the next season, probably due to kill from weeding or drought. Vegetative seedlings have well developed root system than seedlings from seeds; therefore they grow fast and can better re-grow after damage by fire or browse. The contribution to mature stand of *Sclerocarya birrea* is thus, more from vegetative regeneration than regeneration from seeds. To improve survival of seedlings from seeds and hence improve cross-breeding, management efforts need to step up to avoid damage due to farming practices, fire, drought, grazing and diseases. Sexually produced seedlings are also important to provide root-stock for grafting of marula.

Subspecies *caffra* populations showed the highest regeneration both from seeds and vegetative means compared to subspecies *birrea* and *multifoliolata*. This difference in regeneration vigour was directly proportional to the abundance of parent stock. In areas where there were more adult trees per hectare regeneration was also high. Therefore with the exception of the site for subspecies *caffra*, regeneration was higher in the wild environment for both subspecies *birrea* and *multifoliolata* relative to the on farm environment. A study on subspecies *birrea* found more germination on farms but fewer saplings compared to the wild environment and attributed it to intentional removal by farmers to reduce competition with cultivated crops (Gouwakinnou *et al.,* 2009). Mild fires could influence regeneration by breaking the hard marula seed nut as well as initiating sprouting by damaging of roots although this needs a long term monitoring study. On farm population of subspecies *birrea* had a slightly high proportion of regeneration from seeds. Gouwakinnou *et al* (2009) reported more favourable seed germination on farmlands in Benin and attributed it to damage of seeds in the wild. Sexually reproduced seedling are important in the future because farmers can use them as root stock for grafting and therefore should be encouraged to retain them.

7.2.2 Phenology, fruit properties and yield

7.2.2.1 Leafing

Leafing phenology for the three subspecies related to the differences in onset and duration of rainfall and dry seasons. The early leafing observed for subspecies *birrea* may be an adaptation to survive the January dry spell since the area receives a bimodal rainfall pattern unlike the sites for subspecies *caffra* and *multifoliolata* which receives bimodal rainfall pattern. Similar results for early leafing of marula populations in bimodal rainfall areas have been reported (Bie *et al.,* 1998; Munjuga, 2000). As reported in other studies (Hall *et al.,* 2002) leafing started at the beginning of rains and shedding started at the beginning of dry season. Shedding of leaves for deciduous plants is a response to water stress (Lobo *et al.,* 2003) where plants hibernate and forego photosynthesis to avoid excessive loss of water through transpiration. The overall duration of the leafing phenology was 6-8 months and is happens concurrently with the farming season for crops such as maize and beans. It would have been interesting to study the relationship between leaf intensity and performance of crops. It was noted that leafing of marula trees coincides with the planting season but details of crop development, e.g. duration to maturity, timing of flowering and harvesting were not covered.

On farm trees had a prolonged leaf season than the wild trees. To understand whether the prolonged duration of leafing affects crops growing in association with the tree, assessment can be done on farms from within the same villages which do not have marula trees. On farm trees started leafing early but shedding for both on farm and wild trees was simultaneous. This may result from the influence of farmland management activities (Williams *et al.,* 1997; Bofa, 1999) and synchronisation to cope with herbivory, and competition for resources especially water (Brochert *et al.,* 2002) in the wild. While the trees on farm enjoy husbandry from farmers and less competition from other trees, those in the wild are faced with much more severe competition for nutrients and water resources. However due to many factors which controls phenology it is always difficult to correlate which factors are mostly responsible for the pattern of specific phenological events (Borchert *et al.,* 2002).

Male trees from all the subspecies started leafing later than female trees. This means that the leafing duration for male trees was shorter than that of female trees. Females of dioecious plant species usually tend to develop higher reproductive effort because unlike males they require extra energy to produce seeds, fruits, and associated structures in addition to flowers (Wheelwright and Logan, 2004). They thus have to invest and allocate more biomass resources to reproduction (Correia and Barradas, 2000, Guangxiu, 2009). Females of these plants have evolved a means of investing in production of more carbon to support the reproductive costs (Varga and Kytöviita, 2010). Female plants have been found to photosynthesize more than males. Jing *et al.* (2008) found that net photosynthetic rate (*Pn*) of female *Ginkgo biloba* was significantly higher than males. Montesinos *et al.* (2010) points out that fertility may be reduced if resources such as water and nutrients are limited. Therefore the tendency of *Sclerocarya birrea* female leafing early than males may be an adoptive ecophysiology mechanism to bear leaves for longer times in order to maximize photosynthesis.

7.2.2.2 Flowering

This study have revealed that flowering of *Sclerocarya birrea*, as is leafing, took place at the end of dry season or the beginning of rain season. The duration of flowering was between 50 to 90 days at the community level but for individual trees it lasted up to a month. This flowering duration is in line with a report by Devineau (1999) who worked on subspecies *birrea* in Burkina Faso. Flowering of subspecies *caffra* and *multifoliolata* occurred a week to a month after the first rains while subspecies *birrea* flowering occurred at the transition of dry and wet season, indicating that as was for leafing, the bimodal nature of rainfall also affected flowering of subsp. *birrea*. For subspecies *birrea* it could be that flowering has to start early, and so should fruiting; in order to avoid damage of flowers and/or young fruits during the dry spell in January.

Apart from mode of the rainfall mode, flowering phenophases varied in terms of subspecies and sex rather than on farm or wild condition. Therefore the habitat condition between on farm and wild environment showed no influence in flowering of *Sclerocarya birrea*, unlike leafing. With the exception of subspecies *birrea* within which there was no variation in flowering between male and female plants, male flowers for subspicies *caffra* and *multifoliolata* were found to flower early and dry late compared to female flowers. This condition probably is to ensure availability of pollen during the life of all female flowers. It may also be a requirement of female plants to conserve energy for fruit production (Correia and Barradas, 2000, Guangxiu, 2009), a responsibility which the male plants do not have. However subspecies *birrea* did not show differences between male and female flowering phases, most probably because its flowering phase was for a shorter duration compared to the other subspecies. Subspecies *birrea* grows in an area which received bimodal rainfall pattern and probably flowering phase has to be completed before the dry spell in January-February.

7.2.2.3 Fruiting

Fruiting duration was longest for subspecies *multifoliolata* taking up to 8 months and shortest duration was for subspecies *birrea* (3 to 4 months). Fruiting of subspecies *birrea* in Burkina Faso has been recorded to last for up to 7 months (Devineau, 1999) while McHardy (2002) reported fruiting period of 27 to 68 days for some individuals of subspecies *caffra* in South Africa. The bimodal nature of rainfall in Holili which involve a dry spell during the fruiting phenophase may be the reason for short life span of fruiting of subspecies *birrea* while the high amount of rainfall available from February to late May in Malinzanga relieves water stress on the populations of subspecies *multifoliolata*. It is reported that fruiting areas with shortened rainfall period in the tropics have a short fruiting duration (3-4 months) while hose with prolonged rainfall periods have a longer duration of 7-8 months (Singh and Kushwaha, 2006). Precipitation is an important factor in phenology (Murali and Sukumar, 1994) because it influence availability of water resources for fruit maturation (Ågren *et al.,* 2008) and therefore over time plants have evolved phonological events that coincide with local climatic conditions (Singh and Kushwaha, 2005). Also in Malinzanga temperatures were relatively low (20 °C) compared to Kiegea and Holili (both > 24 °C) and might have influenced the rate of growth of fruits. The low temperatures may also lead to a decreased loss of water from the trees and soil surface.

There were no differences in fruiting phenology between on farm and wild populations, and it followed the flowering phenology with trees which flowered earlier bearing fruits earlier. Similar results were reported by McHardy (2002) where he found no considerable difference in fruiting between trees on rangelands and those on homesteads for subspecies *caffra*. More importantly is fruiting of the species during farming season when most of the household food researches have finished. The fruits can play important roles as food as well as an alternative raw material for making refreshment beverages which usually use grains such as maize and sorghum.

A comparison between the subspecies showed that subspecies *multifoliolata* produced significantly the heaviest fruits followed by *birrea* and the lightest were fruits from subspecies *caffra*. Fruit properties can vary within an individual, between individuals within a population and between populations of a species (Wulff, 1989). Various factors, biotic and abiotic; influences the variation of fruit properties usually in complex interactions, needing long term studies to unravel particular causes for variation. Also it should be remembered that these results are based on one site per subspecies and probably if more sites are involved the results may change. This is because the said biotic and abiotic factors may vary between sites.

On farm fruits for subspecies *birrea* and *caffra* were heavier than the fruits from wild populations but the difference was not significant. However for subspecies *multifoliolata* it was the fruits from the wild population which were heavier and the difference was significant. Leakey *et al.* (2005) found that subspecies *caffra* trees on farm were significantly heavier than those from the wild in South Africa while tree in Namibia showed no significant difference by land use. Our results show one subspecies only (subspecies *multifoliolata*), with significant difference in fruit weight; and actually it was the wild fruits which were heavier. On farm fruits for *Sclerocarya birrea* are expected to be heavier than wild fruits due to farmers' selection pressure (Shackleton *et al.,* 2003; Leakey *et al.,* 2005); a phenomenon which have also been observed in fruits from other species (Tanksley, 2004). At the moment, the level of domestic utilization and trade is less in Tanzania compared to South Africa and Namibia, hence probably less influence on on-farm trees of farmers' selection pressure. On farm fruits are expected to be big not only due to selection pressure but also due to less competition and general care received from farmers (Bofa, 1999). However other factors such as intensity of pollination due to more trees hence pollen abundance (Kunin 1993; Ghazoul 2005), herbivory selection pressure (Wheelright, 1993) and soil water retention (Wolfe and Denton, 2001) which are superior in the wild environment as well as differences in biochemical processes within fruits (Richings *et al.,* 2001) may play an important role in giving opposite results. For domestication purposes, the vegetative propagation technique developed from this study can be used to produce plants with desired fruit size and weight. For instance is the subspecies *multifoliolata* fruits, which were the biggest, in combination to other factors such as taste and nutrient composition are desired, scions may be collected from them and grafted to wild rootstock in various locations across the country.

There was a significant variation of fruit size between the populations and between the environments. Subspecies *birrea* had the largest fruits followed by subspecies *multifoliolata* and the smallest fruits were from subspecies *caffra*. Pearson's correlation of fruit diameter and fruit weight was 0.239 ($P < 0.001$) meaning that the relationship was not so big and therefore a large fruit was not necessarily heavier than a small fruit. If the main contributor of fruit weight for the Tanzanian populations is flesh as is in South Africa and Namibia (Leakey *et al.*, 2005), it may imply that variable kernel sizes were responsible for irregularities in the relationship between weight and diameter. Fruit size is important because it relates to quality and appearance and hence influences the market and consumer satisfaction (Seymour *et al.*, 2002). For development of suitable cultivars it is therefore important to take both weight and size of the fruit into consideration. Fruit size, and not weight; was among farmers selection criteria for superior *Sclerocarya* trees hence when working with farmers this criteria needs to be modified to include weight. Wild fruits were larger than on farm fruits except for subspecies *birrea*. The hypothesis was that on wild fruit are not larger that on farm fruits because of farmers selection bias and management. So these results prompts for a study which involve more populations but it is also worth to point out that on farm marula fruits are necessarily larger that wild fruits. Breeding and vegetative propagation efforts can help production of desirable fruits for household consumption or trade.

There was a significant difference in yield per tree between the subspecies but the difference in yield per tree between the two environments was only significant for subspecies *multifoliolata*. These also need data from more populations per subspecies. While there is no previous record on yield for subspecies *multifoliolata* and *birrea*; yield records for *caffra* from countries like Namibia and South Africa shows huge fluctuations between populations and seasons although most of the data is questioned for the scientific methods used (Shackleton *et al.*, 2003). The relationship between fruit yield and DBH was weak ($R^2 < 22$) similar to findings by Shackleton *et al.*, (2003), but there was a strong relationship between yield and crown diameter ($R^2 > 60$). Bigger trees are expected to produce more fruits but also environmental conditions such as soil properties, herbivory, pollination success and seasonal rainfall fluctuation affects yield of fruits (Bofa, 1999; Wolfe and Denton, 2001; Shackleton *et al.*, 2005).

More yield from wild trees of subspecies *multifoliolata* may hints out that presence of more pollinators and degree of tree isolation can affect productivity (Lobo *et al.*, 2003; Waites & Ågren 2004; Wee 2005). The wild population for subspecies *multifoliolata* is close to Ruaha national park (more pollinators) and its on farm population density was the lowest (more isolated trees). In presence of more pollinators means that more flowers stand a high probability chance of fertilisation and therefore more fruits. Pollination intensity and pollination success also increase with increasing population density and decrease with degree of isolation (Kunin 1993; Waites & Ågren 2004; Östergård & Ehrlén 2005; Singer & Wee 2005; Ward & Johnson 2005; Ghazoul 2005). However a study on yield by land use for subspecies *caffra* in S. Africa and Namibia by Shackleton *et al.* (2003); McHardy (2003) and Leakey *et al.* (2005) shows that on farm population produce significantly more fruits (>17, 000 fruits/tree) than wild populations (>3,500 fruits/tree). They attributed the findings to availability of more care by farmers and lack of competition from other plants on farmlands. Selection pressure by farmers is another factor responsible for fruit production (Leakey *et al.*, 2005; Emanuel *et al.*, 2005) although it may not be reflected in this study because of the less utilisation of the fruits in Tanzania. These findings highlights a need for more specific studies on the influence of competition, domestication care, selection and other factors on yield of *Sclerocarya birrea*. Domestication of *Sclerocarya birrea* may need to involve introduction of apiary for honey and wax business while at the same time the bees will boost the pollination of the species.

Resource availability such as rainfall affects productivity of trees and forests (Chiarucci *et al.*, 1993; Ceballos *et al.*, 2004; Ågren *et al.*, 2008; Zunzunegui *et al.*, 2010), this was reflected in our results. With less rainfall in 2009, all the populations produced significantly less fruits compared to the previous year where rainfall was higher. Limited rainfall can result into abortion of flowers or fruits at their early stage in order to allocate enough resources for few selected fruits (Winsor 1986, Sutherland 1986; Lobo *et al.*, 2003; Ågren *et al.*, 2008). Data on fruit yield is likely to vary from year to year in relation to the amount of rainfall available in particular years and especially during reproduction phase. Monitoring of yield may need to be done for several years in order to cover a wider range of rainfall fluctuations from year to year in a longer span.

7.2.3 Vegetative propagation

The most important result of this study was the development of a cost effective propagation method for *Sclerocarya birrea* which is easily applicable to farmers field conditions. While propagation by cuttings and air-layering failed, probably because of lack of use of hormones, grafting using wild seedlings was 99% successful. Although Holtzhausen (1990) reported successful propagation of cuttings for *Sclerocarya birrea*; these results and others by (Akinnifesi 2008, *pers. comm.*) which ended up at the callusing stage suggests that the species is a difficult-to-root plant. There are other studies which have also associated callus formation with *difficult-to-root* species (Hiller, 1951; Cameron and Thomson, 1969; Davis *et al.*, 1982). Therefore the use of cuttings and marcots by poor farmers shows to be impractical and expensive at the moment. But since propagation by cuttings and marcoting is useful for commercial purposes, more efforts are needed to solve the rooting problem.

In the grafting study we used root stock from wild seedlings without regulation of humidity around the grafted plants using polythene bags as is conventionally suggested (Hall et al., 2002). Grafting, depending on place of application, procedure, and materials used can be expensive to surpass micro-propagation (Hartmann *et al.*, 1997). Use of polythene/plastic bags involve additional costs and could attract destruction by enthusiastic passer-bys or playing children and could also result in conflict between farmers if swallowed by grazing livestock. Success of grafting relies highly on the skill of personnel (Mng'omba *et al.*, 2010), hence with the success we recorded, farmers need to practice the procedure for a few times and they will stand a big chance of attaining good grafting results. These results are an improvement to the low success reported by (Jaenicke *et al.*, 2001) and (Mhango & Akinnifesi, 2001) in the early 1990s where large numbers of unimproved seedlings of *Sclerocarya birrea* were distributed to farmers as one of the efforts to establish the tree on farms as an agroforestry species in southern Africa. This early enthusiasm was short-lived as graft-take became as low as 10% and low survival and growth were reported on farmers' fields.

The grafting experiment compared between top wedge and whip and tongue methods using small (5 – 10 mm thick) and large (11 – 20 mm thick) scions. Given the higher level of grafting success, all the methods and sizes of scions produced wonderful result. However this study suggests using whip and tongue method and small scions since its plants performed significantly better than the others in terms of growth and early fruit production. Whip and tongue grafting revealed superior performance in a study on *Vitellaria paradoxa* (Sanou *et al.*, 2004) but top wedge was more successful than whip and tongue in grafting of *Vitex payos* (Kimondo, 2010). There is no clear explanation for the differences although there is a possibility that in whip and tongue there is relatively better close contact between scion and root stock which facilitates faster regeneration. Small size scions showed better leaf machinery development probably due to more active growth properties. It is more likely that the small scions are much younger, still growing and developing compared to the bigger sized scions. Meristematic cell division activities are higher on the smaller/younger scions and hence capable of developing the buds into leaves faster or quickly than those in more matured and more lignified bigger scions (Greenwood *et al* 1988; Mencuccini *et al.,* 2007, Amri, 2010).

Grafting of *Sclerocarya birrea* significantly reduced the fruit bearing age from the normal 6 – 10 years or longer to 2 years. This means that for fruit production farmers won't need to wait for many years to start harvesting. On top of that fruits obtained will be from selected traits like size and appearance of fruits which are important in fruit market. Bearing fruits from the grafted plants can simplify management intervention such as pruning, pest management and assisted pollination because the resulting mature trees are not overly tall. Early fruity bearing can also enable testing of the success of transfer of selected traits from parent stock without the frustration caused by long waiting time for normally established plants. Such traits may include taste, size and nutritional composition.

7.3 Special regional and subspecies differences

Sclerocarya birrea is extensively traded both in local markets and for exports in some countries such as South Africa and Namibia. Also in many countries such as Mali and Zimbabwe local trade on fruits and its products is common. This study has revealed that trade of marula fruits and its products in Tanzania do not exist at the moment. However in the past some farmers in central Tanzania mentioned trade of the fruits in some areas (Teklehaimanot, 2004) indicating a variation between places and regions. Therefore potentially trade is possible and needs to be promoted.

Subspecies *multifoliolata* which is only found in Tanzania was mentioned to be suitable for timber. There is no report of usage of subspecies *caffra* or *birrea* for timber anywhere (Hall *et al.,* 2002). It could be important to assess and compare the wood properties of the subspecies to find out if there are unique properties which makes subspecies *multifoliolata* suitable for timber.

The few inventory studies on *Sclerocarya birrea* available which were done in South Africa, Namibia and Benin found that on farm populations are less dense, female dominated and with big trees. This study found on farm population for subspecies *caffra* was denser than its wild population and was also composed of smaller sized trees. All the populations were male dominated. These results also suggest that the Tanzanian populations are stable unlike some populations in South Africa and Namibia. Wildlife destruction, over-collection of fruits and deforestation has been mentioned as reasons for the unstable populations in the other studies (Nghiitolwa *et al.*, 2003; DFID, 2003; Helm *et al.,* 2009). Any intervention aimed at promotion of use the fruits need to consider the implications on the resources which are mostly naturally available. One of the best interventions to consider is the use of the grafting technique developed in this study to improve and maintain the populations of *Sclerocarya birrea.*

In this study it was found that fruiting from wild populations performed better that on farm populations. Fruits from on farm populations of subspecies *caffra* were the smallest while those from wild populations of subspecies *multifoliolata* produced the biggest fruits. Yield per tree was also highest from wild trees. Studies from South Africa and Namibia found that on farm trees produce bigger, heavy and more fruits than wild trees (McHardy, 2003; Leakey, 2005). The reason they put for the better performance they observed from on farm trees is the long history of farmers' breeding and tending. These results hints that the factors affecting yield of marula trees may not be only the influence of farmers breeding but are many and complex. Factors such as competition and pollination intensity can be a dominant factor affecting fruiting of *Sclerocarya birrea.*

Grafting success recorded in Tanzania through this study is the highest and can contribute significantly in domestication efforts taking place elsewhere in the region. Unlike the previous approaches (Holtzhausen et al., 1990; Chirwa *et al.,* 2007; Akinnifesi *et al.,* 2008b), the technique developed in Tanzania uses wild seedlings instead of nursery established seedlings and grafting materials which are normally costly. It is a cost effective technique easily taken up by farmers because the materials used are locally available and no special treatments like the ones used in nurseries, green houses or mist propagators are required.

7.4. Methodological constraints

- Consultation of more key professionals at the beginning of the study could result into more refinement of fieldwork approaches. Such professionals could be from international research institutions such as ICRAF, national forest research institutes and universities in the regions.
- Ranking of useful trees could also include a separate activity of ranking useful IFTs
- More effort on the design of the questionnaire to generate accurate information by improving confidence of respondents
- Use of more study sites would enable taking care of confounding factors in most of the objectives and hypothesis e.g. comparing various parameters between the subspecies
- Soil sampling techniques could be improved to select a much distant location of away-from-tree samples and include control samples. This would ensure comparison of soils with and without the effect of the tree.
- All propagation trials could be established simultaneously at the beginning of the study to enable monitoring of the plants within time. The grafting in this study was done towards the end of the second year the last year and resulted in delays for up to a year to monitor flowering and fruiting of the plants.

7.5 Conclusion

From the results of survey on local knowledge we found that local knowledge on uses of *Sclerocarya birrea* in Tanzania varied between the study villages/subspecies. Among important differences is the use of marula timber by communities in the site where subspecies *multifoliolata* occurs. This finding prompts the need for more research on *multifoliolata* which is significantly less studied compared to the other subspecies. On the other hand it was found that farmers in Kiegea maintained a farming system with marula trees more abundant that wild populations. The Kiegea farming system provides evidence that farming of food crops and domestication of marula trees can be done on the same piece of land.

Also the study found that farmers are vested with their own means of selection of superior trees. Crown and trunk size were the most important selection criteria for they are related to more shade, more yield and more wood biomass. However these factors need further assessments to find out how farmers use them to select the trees since juvenile stages.

In all the study areas it emerged that farmers have a very limited to none access to forest extension services and therefore lacking forestry knowledge beyond the scope of their local traditional knowledge. This could be among the most important barrier in exploiting the potentials of marula fruits as is done in other countries. Most of the developments in marula processing in other countries emerged from local knowledge, and this knowledge needs to be shared between communities because it varies from place to place. Extension services which could be modified by adapting ICT approaches can play a big role in this dissemination and sharing of local knowledge. Another barrier to domestication is farmers' wrong perception that all trees are protected and need a permit to use them. This misunderstanding starts from the village organs or authorities responsible in overseeing environmental tasks. This means that farmers think they do not have ownership rights over trees on their farms and therefore no need to plant or maintain seedlings because in the end it is a waste of effort and resources. It is important that farmers understand clearly the difference between protected species and forests in order to realize which trees belongs to them. Sending extension personnel to every village is very costly and almost impractical, but the government and NGOs can make good use of the fast growing ICT industry in Africa e.g. fm radios, mobile phone short messages and internet facilities. Improved awareness may increase substantially the number of trees retained in agroforestry systems because security of ownership and/or user-right will be realized by farmers.

This study shows that the populations of marula in Tanzania are stable. While removal/harvesting of fruits and hence seeds are not taking place due to lack of fruit use, a threat would be expected in the populations of subspecies *multifoliolata* whose trees are said to be suitable and rarely used for timber. Over-exploitation of the tree through fruit collection, use of the wood for fuel wood and carvingwood as well as destruction by browsers have been reported to threaten both on farm and wild populations in other countries (Leakey, 2005; Nghitoolwa *et al.,* 2003; Helm *et al.,* 2009). However, the propagation technique developed in this study can be used as a tool to improve and maintain populations whenever and wherever required.

The abundance of on farm and wild populations showed variation. Both on farm and wild populations for all subspecies were randomly distributed and therefore not influenced by disturbance agents. The high abundance observed for on farm population of subspecies *caffra* suggests that marula trees can be retained on farmlands without necessarily posing negative impacts on crop production. Farmers in Holili and Malinzanga should plant and/or retain more marula trees on their farms since on farm adult populations are significantly lower. The large scale clearance of marula trees during establishment of farmland may be regarded as an unjustified excuse unless proved otherwise by further studies on marula trees and intercrops interaction. The specific influence, negative or positive; of *Sclerocarya birrea* on crop yield needs to be assessed in order to advice farmers appropriately during any domestication initiative.

Coppicing from stumps and sprouting from roots was the main form which the population of *Sclerocarya birrea* is recruited. Survival of seedlings from seeds was low since they could not withstand damage by drought, fires, browsing and removal during land preparation and weeding. Seedlings from seeds need to be maintained because they are the ones which will be used in the developed grafting technique. Therefore domestication campaigns must encourage farmers to retain them on their farms while also avoiding activities which can lead to fires in the wild populations. Marula is underutilized in Tanzania but has a lot of potential as an alternative and useful agroforestry tree. Improved natural and artificial regeneration are therefore justified.

Literature surveys revealed that phenology of *Sclerocarya birrea* is among the species' least studied aspects despite its importance in management planning. For two years we monitored the details of leafing, flowering and fruiting of *Sclerocarya* trees comparing between subspecies, land-use, sex and spatial and temporal weather changes. Leafing was the longest phenophase starting at the beginning or few weeks after the rain seasons (October-December) and ending at the beginning of dry and cold months (May-July). Leafing was longer for on farms and on female trees. Therefore if domestication of marula is to take place, the influence of leaf density and duration on intercrops needs to be established since it will take place on farms and female trees will be the most preferred for their fruits. The high abundance of subspecies *caffra* on farms gives hope for a positive interaction between marula trees and intercrops but this need to be researched.

Comparison of fruiting among subspecies showed that it lasted longer for subspecies *multifoliolata* (8 months) while the shortest fruiting duration was observed from subspecies *birrea* (4 months). Availability of fruits for many months is important for ensured supply for household consumption or trade at a longer span during a year. Subspecies *multifoliolata* did not only show the longest fruiting, but also it had better yield in terms of fruits per tree and size. Farmers in the region where the subspecies occur stand a better chance for a more successful and profitable marula domestication. Subspecies *multifoliolata* can be introduced in other regions. This won't be difficult since with the developed grafting technique, performance will be evaluated and understood within few years and therefore able to make a decision whether or not to introduced the subspecies in other regions. This is an important pre-requisite for any introduction of the subspecies in other areas since the observed long fruiting duration may be related to local climate and habitat conditions.

Propagation by cuttings and air layering of *Sclerocarya birrea* failed. Grafting using wild root stock resulted into 99% success with some of the plants producing fruits after two years.The grafting methods used in this study involved slight modification of the conventional grafting techniques to make them practically and economically affordable by small scale farmers. Hormones for growth enhancement or plastic covers for moisture retention were not used and yet a very high grafting success was recorded. Low cost effective propagation techniques for woodland species in Africa are lacking hence slowing down domestication campaigns (Akinnifesi *et al.,* 2006; Amri, 2010). These results contribute in solving this problem and present a chance for accelerated domestication and utilisation of *Sclerocarya birrea*. The technique will be afforded by any farmer, the government and relevant NGOs can easily train a few farmers who will in turn share the skills with other farmers eventually spreading in a wider area with a short time.

The immediate challenge to solve before domestication is to create a market for marula products preferably refreshment beverages, cooking oil and cosmetics. This should begin by local promotion of possible products from marula with expectation that the popularity will grow, spreading in many parts of the country and therefore creating a room for national, regional and even international trade. To start with, farmers can use marula fruits in place for cereal crops as raw materials for production of common local refreshing beverages. Replacing cereals with marula fruits is timely crucial because fruiting is during farming season when normally household cereal reserves are at the minimum. While such an intervention will generate income and hence reducing poverty it will at the same time improve food security because cereal reserves will be available for household food. Also a simple machine for extraction of the nuts can be developed to simplify the task and cost of production of oil and cosmetic products from marula. These few entrepreneurial skills can be easily taken up by farmers and therefore are encouraged. Without a market, domestication of marula is almost impossible because lack of immediate benefits was mentioned as an important barrier on farmers' willingness to engage in improved management and utilisation of IFTs.

In view of the initial steps to be taken for improved management and utilisation of marula in Tanzania both activity and study research are needed to support the promotion. Product development and testing based on local priorities together with the required equipment and tools such as nut extraction plants need to be conducted. Communities needs to be consulted to identify the types of beverages they make in order to guide processing using marula fruits as an alternative as well as establish any required additional ingredients. Cost-effective and simple extraction units need to be designed and tested by farmers. They should be easy to make by local dealers such as mechanics in order to be available to and afforded by farmers. Research is also needed to monitor the performance of grafted plants especially in terms of yield. Testing the impact of beekeeping on pollination and fruiting of the plants is important because if domestication is intensified pollination will also need to be improved. Improved domestication through grafting and introduction of apiary will enhance poverty reduction and food security through availability of bee products for household consumption and trade in addition to the marula products.

This study revealed that retention of marula trees, as was also other trees; was hampered by misconception of the protected trees/habitats act of the Tanzania Forest Act (2002) paragraph 66. Under the act, it is illegal to harvest certain trees due to their conservation status or habitat condition unless a permit is obtained. Farmers do not understand this act properly and thinks it applies to all trees including marula. As a result they are not willing to domesticate trees which eventually they won't have authority over ownership. The government needs to launch educational campaigns about the act so that farmers understand it properly. Unless this is done, the intended impacts of the act may indeed be negative because intentional removal of trees by farmers will reduce instead of increasing tree populations.

7.6 Recommendations

- It is important to devise a means of provision of extension services to farmers to enable them understand the potentials of indigenous fruit tree resources and ways of managing and benefiting from them. The use of ICTs could be effective.
- Awareness campaigns to clarify the Forest act 2002 (66) to the public are important. Farmers showed lack of interest in investing on managing trees because they wrongly perceive all trees as being protected and therefore denying them user rights. Farmers must understand that they can own trees on their farms with the exception of the few protected species or areas.
- Studies on tree-crop interaction to understand growth and yield performance of crops growing together with *Sclerocarya birrea* are needed. This information is important when domestication of the species is to be carried out by farmers alongside other conventional crops.
- Continued monitoring of growth and yield performance of the grafted plants to capture basic guiding information on development of grafted *Sclerocarya birrea* need to be done to enhance affordable domestication.
- Researchers need to collaborate with relevant government departments and NGOs in the transfer of the propagation technology to farmers for wider application.
- Initiatives to stimulate NGOs and the business sector in researching, promoting and trading various products from *Sclerocarya birrea* are needed if commercialization is to be achieved.

- Each year farmers suffer food shortages because they use part of their cereal (staple) harvest to produce and trade beverages locally. In other countries farmers use *Sclerocarya birrea* instead for beverage purposes; farmers in Tanzania can thus be encouraged to save food and use the fruits to produce the beverages. This initiative will not only save the communities from food shortages but also the government's budget normally used to buy supplementary food during shortages.
- More years of studies on fruiting are needed to come up with a strong conclusion on the effect of weather fluctuation on yield.
- Subspecies *multifoliolata* is used for timber in Malinzanga. Studies on its wood properties may be of interest to know if it differs from the other subspecies which are not used for timber and indeed previous studies showing they have poor strength properties.

REFERENCES

ACOCKS, J.P.H., 1988. Veld types of South Africa. *Memoirs of the Botanical Survey of South Africa,* **57**, pp. 1-146.

AFREA, (Undated). Review and Appraisal on the Status of Indigenous Fruits in Eastern Africa. Chikamai, B., Eyog-Matig, O. and Mbogga, M., (Eds.) A report prepared for IPGRI-SAFORGEN in the framework of AFREA/FORNESSA.

ÅGREN, A., BERGGREN, M., LAUDON, H. and JANSSON, M., 2008. Terrestrial export of highly bioalvailable carbon from small boreal catchments in spring floods. *Freshwater Biology*, **53**, pp. 964–972.

ÅGREN, J., EHRLE'N, J. and SOLBRECK, C., 2008. Spatio-temporal variation in fruit production and seed predation in a perennial herb influenced by habitat quality and population size. *J. Ecol.*, **96**, pp. 334–345.

AKINNIFESI, F,. KWESIGA, F., MHANGO, J., MKONDA, A., CHILANGA, T. and SWAI, R., 2004. Domesticating priority miombo indigenous fruit trees as a promising livelihood option for small-holder farmers in southern Africa. *Acta Hort.* **632**, pp. 15-30.

AKINNIFESI, F., KWESIGA, F., MHANGO, J., CHILANGA, T., MKONDA, A., KADU, C., KADZERE, I., MITHÖFER, D., SAKA, J., SILESHI, G., RAMADHANI, T. and DHLIWAYO, P., 2006. Towards the development of miombo fruit trees as commercial tree crops in southern Africa. *For, Trees Livelihoods*, **16**, pp. 103-121.

AKINNIFESI, F., LEAKEY, R., AJAYI, O., SILESHI, G., TCHOUNDJEU, Z., MATAKALA, P., KWESIGA, F., 2008. *Indigenous Fruit Trees in the Tropics: Domestication, Utilization and Commercialization.* World Agrofoforestry Centre: Nairobi. CAB International Publishing, Wallingford, UK pp. 438.

AKINNIFESI, F.K., AJAYI, O.C., SILESHI, G., MATAKALA, P., KWESIGA, F.R., HAM, C., KADZERE, I., MHANGO, J., MNG'OMBA, S.A., CHILANGA, T. and MKONDA, A., 2008a. Creating opportunities for domestication and commercializing miombo indigenous fruit trees in southern Africa. *In,* Akinnifesi, F.K., Leakey, R.R.B., Ajayi, O.C., Sileshi, G., Tchoundjeu, Z., Matakala, P., Kwesiga, F.R. (Eds.). Indigenous Fruit Trees in the Tropics: Domestication, Utilization and Commercialization. World Agroforestry Centre: Nairobi. CABI Publishing, Wallingford, UK. pp. 137-170.

AKINNIFESI, F.K., SILESHI, G., MKONDA, A., AJAYI, O.C., MHANGO, J., CHILANGA, T., 2008b. Germplasm supply, propagation and nursery management of miombo fruit trees. *In*, Akinnifesi, F.K., Leakey, R.R.B., Ajayi, O.C., Sileshi, G., Tchoundjeu, Z., Matakala, P., Kwesiga, F.R. (Eds.). Indigenous Fruit Trees in the Tropics: Domestication, Utilization and Commercialization. World Agroforestry Centre: Nairobi. CABI Publishing, Wallingford, UK. pp. 341-368.

ALTAMURA, M., CAPITANI, F., SERAFINI-FRACASSINI, D., TORRIGIANI, P. and FALASCA, G., 1991. Root histogenesis from tobacco thin cell layers. *Protoplasma,* **161**, pp. 31- 42.

AMRI, E., 2009. Investigation on the propagation potential of *Dalbergia melanoxylon* Guill. and Perr. provenances and their genetic diversity from selected areas of Tanzania. Ph.D. Thesis, University of Dar es Salaam, Tanzania.

AMRI, E., LYARUU, H., NYOMORA, A. and KANYEKA, Z., 2010. Vegetative propagation of African Blackwood (Dalbergia melanoxylon Guill. & Perr.): effects of age of donor plant, IBA treatment and cutting position on rooting ability of stem cuttings. *New Forests*, **39**(2), pp. 183-194.

ARAYA, H., GEBREMICHAEL, Y. GEBREAMLAK, A. and WATER-BAYER, A., 2006. Participatory research that builds on local innovation in beekeeping to escape poverty. Conference on International Agricultural Research for Development. 11 - 13 October 2006, University of Bonn, Germany.

ARNOLD, T.H. and DE WET, B.C., (Eds.). 1993. Plants of Southern Africa: names and distribution. National Botanical Institute. Pretoria, South Africa. 825p.

ARNOLD, T.H., WELLS, M.J. and WEHMEYER, A.S., 1985. Khoisan food plants: taxa with potential for future economic exploitation. *In* Wickens, G.E., Goodin, J.R., and Field, D.V. (Eds.). Plants for arid lands. pp. 69-86. Proceedings of the International Conference on Economic Plants for Arid Lands, 23-27 July, 1984, Royal Botanical Gardens, Kew, UK. 452 pp.

ASHMAN, T. L. and SCHOEN, D., 1997. The cost of floral longevity in *Clarkia tembloriensis* : An experimental investigation. *Evolutionary Ecology,* **11**, pp. 289–300.

ASHTON, P., GIVNISHA, T. and APPANAH, S., 1988. Staggered flowering in the Dipterocarpaceae: new insights into floral induction and the evolution of mast fruiting in the seasonal tropics. *American Naturalist,* **231**, pp. 44-66.

AUBRÉVILLE, A., 1937. The Niger Colony Forestry Expedition, September to December, 1935. Forestry Department, Ibadan. 83 pp

AUBRÉVILLE, A., 1950. Flore forestière soudano-guinéenne. Société d'Éditions Géographiques, Maritimes et Coloniales, Paris. 533 pp

BADECK, F.W., BONDEAU, A., BÖTTCHER, K., DOKTOR, D., LUCHT, W., SCHABER, J. and SITCH, S., 2004. Responses of spring phenology to climate change. *New Phytologist*, **162**, pp. 295–311.

BAIJNATH, H., 1983. Abstract of a poster paper: Sexes in *Sclerocarya caffra* Sond. Anacardiaceae. 9th South African Association of Botanists Congress, University of Witwatersrand, Johannesburg .

BANDA T., SCHWARTZ, M. and CARO, T., 2006. Woody vegetation structure and composition along a protection gradient in a miombo ecosystem of western Tanzania. *Forest Ecology and Management*, **230**, pp. 179-185.

BANDEIRA, S.O., ALBANO, G. And BARBOSA, F.M., 1999. Diversity and uses of plant species in Goba, Lebombo Mountains, Mozambique, with emphasis on trees and shrubs. *In,* Timberlake, J. and Kativu, S. (Ed.). African plants: biodiversity, taxonomy and uses. pp. 429-439. Royal Botanic Gardens, Kew. 591 pp

BÂTHIE, H.P. DE LA, 1944. Revision des Anacardiacées, Burséracées et Icacinacées de Madagascar et des Comores. Mémoires du Muséum Nationale d'Histoire Naturelle, **18**, pp. 243-270

BAWA, K. and HADLEY, M., 1990. Reproductive ecology of tropical forest plants. MAB Series, Vol. 7.UNESCO, London.

BAWA, K.S. and KRUGMAN, S.L. 1991. Reproductive biology and genetics of tropical trees in relation to conservation and management. *In* A. Gomez-Pompa, T.C. Whitmore and M. Hadley. Rain forest regeneration and management. Man and the Biosphere Series. UNESCO, Paris and the Partheneon Publishing Group.

BAYALA, J., HENG, L.K., VAN NOORDWIJK, M. and OUEDRAOGO, S.J., 2008. Hydraulic redistribution study in two native tree species of agroforestry parklands of West African dry savanna. *Acta Oecologica,* **34**(3), pp. 370-378.

BAYALA, J., TEKLEHAIMANOT, Z., OUEDRAOGO, S.J., 2002. Millet production under pruned tree crowns in a parkland system in Burkina Faso. *Agroforestry Systems,* **54**, pp. 203–214.

BEENTJE, H. J., 1994. Kenya trees, shrubs and lianas. National Museums of Kenya. Nairobi.

BELEMTOUGRI, R.G., CONSTANTIN, B., COGNARD, C., RAYMOND, G., SAWADOGO, L., 2001. Effects of *Sclerocarya birrea* (A. rich) hochst (anacardiaceae) leaf extracts on calcium signalling in cultured rat skeletal muscle cells. *J Ethnopharmacol* **76**, pp. 247–252.

BERKES, F., COLDING J. and FOLKE, C., 2000. Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications*, **10**(5), pp. 1251–1262.

BERRY, J.W., 2008. Globalisation and acculturation. *International Journal of Intercultural Relations,* **32**(4), pp. 328-336.

BIE, S., DE KETNER, P., PAASSE, M. and GEERLING, C., 1998. Woody plant phenology in the West Africa savanna. *Journal of Biogeography*, **25**, pp. 883-900.

BIGALKE, R.C. 1978. Mammals. *Monographiae Biologicae*, **31**, pp. 981-1048. Junk, The Hague. 1439 pp

BISHOP, J. G. and SCHEMSKE, D. W., 1998. Variation in flowering phenology and its consequences for lupines colonizing mount St. Helens. *Ecology,* **79**, pp. 534–546.

BOFFA, J.M., 1999. Agroforestry parklands in sub-Saharan Africa. FAO Conservation Guide 34. Food and Agriculture Organization of the United Nations, Rome, Italy.

BOND, W. and MIDGLEY, J., 2001. The persistence niche: ecology of sprouting in woody plants. *Trends in Ecology and Evolution*, **16**, pp. 45–51.

BORCHERT, R., 1994. Soil and stem water storage determine phenology and distribution of tropical dry forest trees. *Ecology* **75**, pp. 1437-1449.

BORCHERT, R., RIVERA, G. and HAGNAUER, W., 2002. Modification of vegetative phenology in a tropical semi-deciduous forest by abnormal drought rain. *Biotropica*, **34**, pp. 27–39.

BOTELLE, A., 2002. A survey of marula fruit yields in North- Central Namibia Report to UK DFID Forestry Research Programme (Project No R7795). CRIAA-SADC, Windhoek, Namibia.

BRAEDT, O. and STANDA-GUNDA, W., 2000. Woodcraft markets in Zimbabwe. *International Tree Crops Journal,* **10**(4), pp. 367-384.

BREARLEY, F. Q., PROCTOR, J., SURIANTATA, N.L., DALRYMPLE, G. and VOYSEY, B. C., 2007. Reproductive phenology over a 10-year period in a lowland evergreen rain forest of central Borneo. *J. Ecol.*, **95**, pp.828–839.

BREITENBACH, F. VON, 1963. *The indigenous trees of Ethiopia*, 2nd edn. Ethiopian Forestry Association, Addis Ababa. 305 pp.

BRIGHAM, T., CHIHONG, A. and CHIDUMAYO, E., 1996. Trade in woodland products from the miombo region. *In* Campbell, B. (Ed). The Miombo in transition: Woodlands and welfare in Africa. CIFOR, Bogor, Indonesia. pp. 137–174.

Brook, R.K. and McLachlan, S.E., 2008. Trends and prospects for local knowledge in ecological and conservation research and monitoring. *Biodiversity and Conservation,* **17**(14), pp. 3501-3512.

BURGER, A.E.C., De VILLIERS, J.B.M. and Du PLESSIS, L.M. 1987. Composition of the kernel oil and protein of the marula seed. *South African Journal of Science*, **83**, pp. 733-735.

BUSSON, F., 1965. Plantes alimentaires de l'ouest Africain: etude botanique, biologique et chimique. Leconte, Marseilles. 568 pp.

BUWALDA, A. O., OTSYINA, R., FILSON, G. and MACHADO, V. S., 1997. Indigenous Miombo fruit trees - health and wealth for the Sukuma people. *Agroforestry Today*, **9** (3), pp. 23-25.

CAMERON, R. and THOMSON, G., 1969. The vegetative propagation of *Pinus radiata*: root initiation in cuttings. *Bot Gaz*, **130**, pp. 242–251.

CAMPBELL, B. M. and BRIGHAM, T.E., 1993. Non-wood forest products in Zimbabwe. *In* Non-wood forest products: a regional expert consultation for English speaking African countries, Arusha, 17 – 22 October, 1993. Annex IV. FAO and the Commonwealth Science Council, Rome and London.

CAMPBELL, B.M., SHACKLETON, S. and WOLLENBERG, E., *2003.* Overview: Institutional arrangements for managing woodlands. *In,* Kowero, G., Campbell, B. M.

and Ussif, R. S., (Eds.). Policies and Governance Structures in Woodlands of Southern Africa Center for International Forestry Research (CIFOR), Bagor, Indonesia. 224 pp.

CARR, W.R., 1957. Notes on some Southern Rhodesian indigenous fruits, with special reference to their ascorbic acid content. *Food Research,* **22**, pp. 590-596.

CAVENDISH, W., 1999. Empirical regularities in the poverty-environment relationship of African rural households. WPS 99-21.

CEBALLOS, H., IGLESIAS, C., PEREZ, J. and DIXON, G.O., 2004. Cassava breeding: opportunities and challenges. *Plant Molecular Biology,* **00**, pp. 1 – 14.

CHAZDON, R.L., PERES, C.A., DENT, D., SHEIL, D., LUGO, A.E., LAMB, D., TORK, N.E. and MILLER, S.E., 2009. The potential for species conservation in tropical secondary forests. *Conserv. Biol.* **23**, pp.1406–1417.

CHIARUCCI, A., PACINI, E. and LOPPI, S., 1993. Influence of temperature and rainfall on fruit and seed production of *Arbutus unedo* L. *Botanical Journal of Linnaean Society* **111**, pp. 71–82.

CHIDUMAYO E., 1997. *Miombo ecology and management: An introduction.* IT Publications, Environment Institute, Stockholm, Sweden.

CHIDUMAYO, E., 1993. *Responses of miombo to harvesting: ecology and management.* Stockholm Environment Institute, Stockholm.

CHIDUMAYO, E., 1998. A re-assessment of effects of fire on miombo regeneration in the Zambian Copperbelt. *Journal of Tropical Ecology* **4** (4), pp. 361-372.

CHIHAMBAKWE, M., 1987. Multiple use management of indigenous forests in Zimbabwe: Experiences and options. In the report of the workshop on the Management and Development of Indigenous Forests in the SADCC Region, Victoria Falls, Zimbabwe. October 19-25, 1987. pp.177-185.

CHIMWALA, M., 2004. Masuku: food from the wild. LEISA Magazine: Retreaved online 30/06/2010 http://www.agriculturesnetwork.org/magazines/global/valuing-crop-diversity/masuku-food-from-the-wild.

CHIRWA, P., BWANALI, R., MEKE, G., SAGONA, W., MUNTHALI, C. and MWABUMBA, L., 2007.Growth and phenology of a three- to four-year-old *Sclerocarya birrea* international provenance trial in Malawi. *Southern Hemisphere Forestry Journal,* **69** (1), pp. 49 – 54.

CHIRWA, P.W. and AKINNIFESI, F.K., 2008. Ecology and biology of *Uapaca kirkiana, Strychnos cocculoides* and *Sclerocarya birrea* in Southern Africa: *In,* Akinnifesi, F.K., Leakey, R.R.B., Ajayi, O.C., Sileshi, G., Tchoundjeu, Z., Matakala, P. and Kwesiga, F.R.(Eds.). *Indigenous fruit trees in the tropics: domestication, utilization and commercialization.* Wallingford: CAB International. p. 322-340.

CIFOR, 2003. Annual report. Indonesia

CLARK, P.J. and EVANS, F.C., 1954. Distance to nearest neighbour as a measure of spatial relationships in populations. *Ecology* **35**, pp. 445-453.

CLARKE, J., CAVENDISH, W. and COOTE, C., 1996. Rural households and Miombo woodlands: use, value and management. *In* Campbell, B. (Ed). The Miombo in transition: Woodlands and welfare in Africa. Pp 101 - 135. CIFOR, Bogor, Indonesia.

CLAUSS, B., 1984. Bee forage in Botswana. Proceedings of the Third International Conference on Apiculture in Tropical Climates, Nairobi, Kenya, 5-9 November 1984, pp 217-221. International Bee Research Association, London.

COATES PALGRAVE, K., 1972. Trees of Southern Africa. C. Struik Publishers, Cape Town.

COATES-PALGRAVE, K., 1988. Trees of southern Africa. C.S. Struik Publishers. Cape Town.

COETZEE, B.J., ENGLEBRECHT, A.H., JOUBERT, S.C.J. and RETIEF, P.F., 1979. Elephant impact on *Sclerocarya caffra* trees in *Acacia nigrescens* tropical plains thornveld of the Kruger National Park. Koedoe**, 22**, pp. 39-60.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates

CORNELISSEN, J.H.C., 1999. A triangular relation-ship between leaf size and seed size among woody species: Allometry, ontogeny, ecology and taxonomy. *Oecologia*, **118**, pp. 248-255.

CORREIA, O., DIAZ-BARRADAS, M.C., 2000. Ecophysiological differences between male and female plants of *Pistacia lentiscus* L. *Plant Ecology*, **149**, pp. 131–142.

COTTAM, G., and CURTIS, J.T., 1956. The use of distance measures in phyto-sociological sampling. *Ecology* **37**, pp. 451-460.

CRUDEN, S., KINSMAN, R., STOCKHOUSE, E. and LINHART, Y. B., 1976. Pollination, fecundity and the distribution of moth-flowered plants. *Biotropica,* **8,** pp. 204-210.

CUNNINGHAM, A. B., HUBBARD, D., KINAHAN, J., KREIKE, E.H.P.M., SEELY, M.K. & STUART-WILLIAMS, V., 1992. Oshanas: Sustaining people, environment and development in Central Owambo, Namibia. Typosprint, Windhoek, Namibia. ISBN 99916-709-04.

CUNNINGHAM, A.B., 1988. Collection of wild plants in Thembe Thonga society: A guide to Iron Age gathering activities? *Annals of the Natal Museum*, **29**, pp. 433 – 446.

CUNNINGHAM, A.B., 1989. Indigenous plant use: balancing human needs and resources. *In* HUNTLEY, B.J. (Ed). Biotic diversity in southern Africa: concepts and conservation. Oxford University Press, Cape Town. pp 93 –106.

DALZIEL, J. M., 1948. *The Useful Plants of West Tropical Africa.* An appendix to the Flora of West Tropical Africa by J. Hutchinson and J.M. Dalziel. Crown Agents for the Colonies, London.

DAVIES, F., LAZARTE, J. and JOINER, J., 1982. Initiation and Development of Roots in Juvenile and Mature Leaf Bud Cuttings of *Ficus Pumela* L. *American Journal of Botany,* **69**, pp. 804 - 811.

DAWSON, I., 1997. *Prunus africana*: How agroforestry can help save an endangered medicinal tree. *Agroforestry Today.* **9** (2), pp. 15-17.

De BIE, S., KETNER, P., PAASSE, M. and GEERLING, C., 1998. Woody plant phenology in the West Africa savanna. *Journal of Biogeography*, **25**, pp. 883-900.

DE WET, H., NKWANYANA, M.N., VAN VUUREN, S.F., 2010. Medicinal plants used for the treatment of diarrhoea in northern Maputaland, KwaZulu–Natal Province, South Africa. *Journal of Ethnopharmacology* **130**, pp. 284–289.

DEN ADEL, S. 2002. Use of marula products for domestic and commercial purposes by households in North Central Namibia. Unpublished report prepared for FRP Project o. ZF0140/R7795, CRIAA SA-DC, Windhoek.

DESCHEEMAEKER, A., 1979. Ravi maitso. T.P.F.C.M. Imprimeries Staint-Paul, Fianarantsoa, Madagascar.

DEVINEAU, J.L., 1999. Seasonal rhythms and phenological plasticity of savanna woody species in a fallow farming system (south-west Burkina Faso). *Journal of Tropical Ecology*, **15**, pp. 497-513.

DFID., 2003. Winners and losers in forest product commercialisation. Final report (Marula - *Sclerocarya birrea).* Centre for Ecology and Hydrology (CEH). Wallingford, Oxfordshire, UK.

DHIEF, A., GORAI, M., ASCHI-SMITI, S. and NEFFATI, M., 2009. Comparative phenological and water potential patterns of three Calligonum species in the eastern great Erg of Tunisia. *Flora - Morphology, Distribution, Functional Ecology of Plants,* **204**(8), pp. 581-592.

DIAMOND, J., 1997. *Guns, Germs and Steel*: The Fates of Human Societies, Random House.

DIEYE, A.M., SARR, A., DIOP, S.N., NDIAYE, M., SY, G.Y., DIARRA, M., RAJRAJI GAFFARY, I., NDIAYE, SY A. and FAYE, B., 2008. Medicinal plants and the treatment of diabetes in Senegal: survey with patients. *Fundamental and Clinical Pharmacology* **22**, pp. 211–216.

DIMO, T., RAKOTONIRINA, S.V., TAN, P.V., AZAY, J., DONGO, E., KAMTCHOUING, P. and CROS, G., 2007. Effect of *Sclerocarya birrea* (Anacardiaceae) stem bark methylene chloride/methanol extract on streptozotocin-diabetic rats. *Journal of ethnopharmacology,* **110**(3), pp. 434-438.

DOVIE, D., WITKOWSKI, E. and SHACKLETON, C., 2008. Knowledge of plant resource use based on location, gender and generation, *Applied Geography,* **28**, pp. 311-322.

DU PLESSIS, P., 2002. Promoting Indigenous Fruit in Namibia. CRIAA SADC. Namibia.

DUCHESNEAU, R., LESAGE, I., MESSIER, C. and MORIN, H., 2001. Effects of light and intraspecific competition on growth and crown morphology of two size classes of understory balsam fir saplings. *Forest Ecology and Management,* **140**, pp. 215-225.

DZEREFOS, C. M., 1996. Distribution, establishment, growth and utilisation of mistletoes (Loranthaceae) in the Mpumalanga lowveld. M.Sc. thesis. University of the Witwatersrand, Johannesburg. 169 pp.

EAMUS, D, and PRIOR, L., 2001. Ecophysiology of trees of seasonally dry tropics: comparisons among phenologies. *Adv Ecol Res.*, **32**, pp. 113– 197.

EDJE, T., 2000. The status of *Sclerocarya birrea* in Swaziland. *In,* Youde, E. (Ed). A workshop to plan the production of a definitive species monograph on *Sclerocarya birrea* and associated extension literature. 13- 14 March 2000. Monographs and extension materials on *Sclerocarya birrea.* DFID FRP Project R7227. School of Agricultural and Forest Sciences, University of Wales, Bangor.

EGGELING, W.J., and DALE I. R., 1951. *The indigenous trees of the Uganda Protectorate.* Government Printer, Entebbe.

ELLIOT, S., BAKER, J. and BORCHERT R., 2006. Leaf flushing during the dry season: the paradox of Asian Monsoon forests. *Global Ecology and Biogeography,* **15**, pp. 248–257.

ELLIOTT, S. and IRWIN, R., 2009. Effects of flowering plant density on pollinator visitation, pollen receipt, and seed production in Delphinium barbeyi (Ranunculaceae). *American Journal of Botany,* **96**, pp. 912-919.

ELOFF, J.N., 2001. Antibacterial activity of Murula (*Sclerocarya birrea* (A. rich) Hochst. Subsp. *Caffra* (Sond) Kokwaro) (Anacardiaceae) bark and leaves. *Journal of Ethnopharmacology*, **76,** pp. 305–308.

EMANUEL, P.L., SHACKLETON, C.M. and BAXTER, J.S., 2005. Modelling the sustainable harvest of *Sclerocarya birrea* subsp. *caffra* fruits in the South African lowveld. *Forest Ecology and Management,* **214**(1-3), pp. 91-103.

ENQUIST, B.J. and NIKLAS, K.J. 2001. Invariant scaling relations across tree-dominated communities. *Nature* , **410**, pp. 655-660.

EROMOSELE, I.C., EROMOSELE, C.O. and KUZHKUZHA, D.M., 1991. Evaluations of mineral elements and ascorbic acid contents in fruits of some wild plants. Plant Foods for Human Nutrition, **41,** pp. 151-154.

FABREGUES, B.P. and LEBRUN, J. P., 1976. Catalogue des plantes vasculaires du Niger. Institut d'Élevage et du Médecine Vétérinaire des *Pays Tropicaux Étude Botanique*, **3**, pp. 1-433.

FAO, 1995. Edible Nuts. Non-wood forest products for rural income and sustainable forestry, No. 5. FAO, Rome. http://www.fao.docrep/v8929e/v8929e06.htm.

FENNER, M., 1998. The phenology of growth and reproduction in plants. *Perspectives in Plant Ecology, Evolution and Systematics,* **1**, pp. 78–91.

FISCHER, J., ZERGER, A., GIBBONS, P., STOTT, J., LAW, B., 2010. Tree decline and the future of Australian farmland biodiversity. Proceedings of the National Academy of Sciences, USA. 145: 19597-19602

FORD, Y., BONHAM, E., CAMERON, R., BLAKE, P., JUDD, H. and HARRISON-MURRAY, R., 2002. Adventitious rooting: examining the role of auxins in an easy- and difficult-to-root plant. *Plant Growth Regulation*, **36**, pp. 149-159.

FOX, F. W. and NORWOOD YOUNG, M. E., 1983. Food from the veld. South African Institute for Medical Research, Johannesburg.

FOX, F.W. and STONE, W., 1938. The antiscorbutic value of Kaffir beer. South African *Journal of Medical Sciences*, **3**, pp. 7-14.

FOX, W. and YOUNG, E., 1982. Food from the veld. South African Institute for Medical Research, Johannesburg.

FRANKIE, G., BAKER, H. and OPLER, P., 1974. Comparative phenological studies of trees in tropical wet and dry forests in the lowlands of Costa Rica. *Journal of Ecology,* **62**, pp. 881-899.

FRIEDMANN, F., 1997. Anacardiacées. Flore des Mascareignes. Institut Français de Recherche Scientifique por le Développement en Coopération/Royal Botanic Gardens, Paris/Kew. 11 pp

FROST, P., 1996. The Ecology of Miombo Woodlands. *In*, B.M. Campbell (Ed.). The Miombo in Transition: Woodlands and Welfare in Africa. Centre for International Forestry Research, Bogor, Indonesia.

GADEK, P.A., FERNANDO, E.S., QUINN, C.J., HOOT, S.B., TERRAZAS, T., SHEAHAN, M.C. and CHASE, M.W., 1996. Sapindales: molecular delimitation and infraordinal groups. *American Journal of Botany*, **83**, pp. 802-811

GELFAND, M., MAVI, S., DRUMMOND, R.B., and NDEMERA, B., 1985. The traditional medical practitioner in Zimbabwe. His principles of practice and pharmacopoeia. Mambo Press, Gweru.

GERMAN, G., AKINNIFESI, F., EDRISS, A., SILESHI, G., MASSANGANO, C. and AJAYI O., 2009. Influence of property rights on farmers' willingness to plant indigenous fruit trees in Malawi and Zambia. *African Journal of Agricultural Research*, **4** (5), pp. 427-437.

GHAZANFAR, S., 1989. *Savanna Plants: An Illustrated Guide*. Macmillan Publishers. Hong Kong. p. 49.

GHAZOUL, J. and SHEIL, D., 2010. *Tropical Rain Forest Ecology, Diversity, and Conservation.* Oxford Univ. Press, Oxford.

GHAZOUL, J., 2005. Pollen and seed dispersal among dispersed plants. *Biological Reviews of the Cambridge Philosophical Society,* **80**, pp. 413 – 443.

GLEW, R.S., VANDERJAGT, D.J., HUANG, Y. S., CHUANG, L.T., BOSSE, R., GLEW, R.H., 2004. Nutritional analysis of the edible pit of *Sclerocarya birrea* in the Republic of Niger (daniya Hausa). *J. Food Composition Anaysis,* **17**, pp. 99–111.

GLOVER, B., 2000. Differentiation in plant epidermal cells: A review. *Journal of Experimental Botany*, **51**, pp. 497–505.

GOMEZ, M.I, 1988. A resource inventory of indigenous and traditional foods in Zimbabwe. *Zambezia* **XV**, pp. 53 -73.

GONDWE, M., KAMADYAAPA, D.R., TUFTS, M., CHUTURGOON, A.A. and MUSABAYANE, C.T., 2008. *Sclerocarya birrea* [(A. Rich.) Hochst.] [Anacardiaceae] stem-bark ethanolic extract (SBE) modulates blood glucose, glomerular filtration rate (GFR) and mean arterial blood pressure (MAP) of STZ-induced diabetic rats. *Phytomedicine,* **15**(9), pp. 699-709.

GOUWAKINNOU, G.N., KINDOMIHOU, V., ASSOGBADJO, A.E. and SINSIN, B., 2009. Population structure and abundance of *Sclerocarya birrea* (A. Rich) Hochst subsp. *birrea* in two contrasting land-use systems in Benin. *Int. J. Biodivers. Conserv.* **6**, pp. 194–201.

GREENWOOD, M., HOPPER, C. and HUTCHISON, K., 1989. Maturation in larch: Effect of age on shoot growth, foliar characteristics and DNA methylation. *Plant Physiology*, **90**, pp. 406-412.

GRONDARD, A., 1964. La vegetation forestière au Tchad. Bois et Forêts des Tropiques, **93**, pp. 15-34.

GRUENWALD, 2006. Anti-aging nutraceuticals. *Food Science and Technology*, **20** (3), pp. 50-51.

GRUNDY, I.M., CAMPBELL, B.M., BALEBEREHO, S., CUNLIFFEE, R., TAFANGENYASHA, C., FERGUSSON, R. and PARRY, D., 1993. Availability and use of trees in Mutanda Resettlement Area, Zimbabwe. *Forest Ecology and Management* **56,** pp. 243 – 266.

GUANGXIU, L., WEI, Z., TUO, C., XUELIN, C., YONGSHAN, L. and LIZHE, A., 2009. Gender-specific carbon discrimination and stomatal density in the dioecious tree of Hippophate rhamnoides. *South African Journal of Botany,* **75**(2), pp. 268-275.

GUMBO, D.J., MUKAMURI, B.B., MUZONDO, M.I. and SCOONES, I.C. 1990. Indigenous and exotic fruit trees: why do people want to grow them. *In* Prinsley, R.T. (Ed). Agroforestry for sustainable production: economic implications. Pp. 185 – 214. Commonwealth Science Council, London.

HALL J.B., O' BRIEN E.M. and SINCLAIR F.L., 2002. *Sclerocarya birrea: A monograph.* School of Agricultural and Forest Sciences No. 19, University of Wales, Bangor 157 pp.

HALL-MARTIN, A.J. and FULLER, N.G., 1974. Observations on the phenology of trees and shrubs of the Lengwe National Park, Malawi. *J.S. Aft. Wildl. Mgmt. Ass.* **5**, pp. 83-86.

HALL-MARTIN, A.J. and FULLER, N.G., 1975. Observations on the phenology of some trees and shrubs of the Lengwe National Park, Malawi. *Journal of the South African Wildlife Management Association*, **5**, pp. 83-86.

HANAN, N., SEA, W., DANGELMAYR, G. and GOVENDER, N., 2008. Do fires in savannas consume woody biomass? A comment on approaches to modeling savanna dynamics. *The American Naturalist*, **171**, pp. 851–856.

HAQ, N., BOWE, C. and DUNSIGER, Z., 2008. Challenges to Stimulating the Adoption and Impact of Indigenous Fruit Trees in Tropical Agriculture in Indigenous Fruit Trees in the Tropics. *In,* Akinnifesi, F. K., Leakey, R. R. B., Ajayi, O. C., Sileshi, G., Tchoundjeu, Z., Matakala, P. and Kwesiga, F. R.(Eds.). Indigenous fruit trees in the tropics: domestication, utilization and commercialization. CAB International, Wallingford, UK. pp. 50-69.

HARBAGE, J., STIMART, D. and EVERT, R., 1993. Anatomy of adventitious root formation in microcuttings of *Malus domestica* Borkh 'Gala'. *Journal of American Society of Horticultural Science*, **118**, pp. 680-688.

HARPER, J., WILLIAMS, T. and SAGAR, G., 1965. The behaviour of seeds in soil. I. The heterogeneity of soil surfaces and its role in determining the establishment of plants from seed. *Journal of Ecology* **53**, pp. 273-286.

HARRISON, W. M. and PIENAAR, L. V., 1987. Quantifying the effects of fusiform rust on tree basal area growth in slash pine plantations. PMRC Technical Report 1987-2.

HARTMAN, H.T. and KESTER, D.E., 1997. Plant Propagation: Principles and Practices, 8th ed. Prentice-Hall, New York.

HARTMANN, H.T., KESTER, D.E., DAVIES, F.T. Jr., and GENEVE, R.L., 1997. *Plant propagation principles and practices*. 6th ed. Prentice Hall, Upper Saddle River, New Jersey.

HELM, C.V., SCOTT, S.L. and WITKOWSKI, E.T.F., Reproductive potential and seed fate of *Sclerocarya birrea* subsp. *caffra* (marula) in the low altitude savannas of South Africa. *South African Journal of Botany,* In Press, Corrected Proof.

HELM, C.V., WITKOWSKI, E.T.F., KRUGER, L., HOFMEYR, M. and OWEN-SMITH, N., 2009. Mortality and utilisation of *Sclerocarya birrea* subsp. *Caffra* between 2001 and 2008 in the Kruger National Park, South Africa. *South African Journal of Botany,* **75**(3), pp. 475-484.

HEM, C. and WITKOWSKI, E., 2008. What don't we know about *Sclerocarya birrea* subsp. *caffra*? SAAB Annual Meeting Abstracts pp. 387.doi:10.1016/j.sajb.2008.01.145

HEMBORG, Å.M. and BOND, W.J., 2006. Do browsing elephants damage female trees more? *African Journal of Ecology*, **45**, pp. 41–48.

HEPPER, F.N., 1979. Second edition of the map showing the extent of floristic exploration in Africa south of the Sahara published by AETFAT. *In* Kunkel, G. (ed.). Taxonomic aspects of African economic botany pp. 157- 162. Bentham-Moxon Trust, Kew. 250 pp

HERBERT, M., CHAMSHAMA, S.A.O., MUGASHA, A.G. and MSANGA H.P., 1998. Effect of seed positioning and sowing depth on germination of *Vangueria infausta* seed. *In* Malimbwi R.E. and Nsolomo, V.R. (Eds). Proceedings of SUA/AUN workshop on Tanzania Forestry sector: Problems and possible solutions. March 23rd to 26th 1998, Olmotony Arusha, Tanzania.

HETT, J.M. and LOUCKS, O.L., 1976. Age Structure Models of Balsam Fir and Eastern Hemlock. *Journal of Ecology,* **64**(3), pp. pp. 1029-1044.

HIGGINS, S., BOND, W. and TROLLOPE, W., 2000. Fire, resprouting and variability: a recipe for grass–tree coexistence in savanna. *Journal of Ecology*, **88**, pp. 213–229.

HIGH, C. and SHACKLETON, C.M., 2000. The comparative value of wild and domestic plants in home gardens of a South African rural village. Agroforestry Systems, **48**, pp.141- 156.

HILLMAN, Z., MIZRAHI, Y. and BEIT-YANNAI, E., 2008. Evaluation of valuable nutrients in selected genotypes of marula (*Sclerocarya birrea* ssp. *caffra*). *Scientia Horticulturae,* **117**(4), pp. 321-328.

HINES A. D. and ECKMAN K., 1993. Indigenous multipurpose trees of Tanzania: Uses and economic benefits for people. Cultural survival of Canada and development services foundation of Tanzania. www.fao.org/docrep/X5327e/x5327e00.htm

HOFFMANN, W. and SOLBRIG, O., 2003. The role of topkill in the differential response of savanna woody plants to fire. *Forest Ecology and Management*, **180**, pp. 273–286.

HOFFMANN, W.A., 1998. Post-burn reproduction of woody plants in a Neotropical savanna: the relative importance of sexual and vegetative reproduction. *Journal of Applied Ecology*, **35**, pp. 422–433.

HOLTZHAUSEN, L. C. 1993. Ennobling and domestication of the indigenous African marula. Indigenous Plant Use Newsletter 1 (October): 1 - 3.

HOLTZHAUSEN, L.C., 2001. Enobling the African marula. *In* Anon. Marula workshop: report and abstracts. pp 20-22. University of Pretoria, Pretoria.

HOLTZHAUSEN, L.C., SWART, E. and RENSBURG, R. VAN, 1990. Propagation of the marula (*Sclerocarya birrea* subsp. *caffra*). Acta Horticulturae, **275,** pp. 323-334.

HOUEROU, H., 1980. Chemical composition and nutritive value of browse in West Africa. *In* H.N. le Houérou (ed.), Browse in Africa: the current state of knowledge. pp. 261-289. International Livestock Centre for Africa, Addis Ababa. 491 pp.

HOUGHTON, C., 1999. New natural oils and their properties. Anglia Oils Ltd. -Bulk Speciality Division.

HOUSE, J., ARCHER, S., BRESHEARS, D. and SCHOLES, R., 2003. Conundrums in mixed woody–herbaceous plant systems. *Journal of Biogeography*, **30**, pp. 1763–1777.

HUTCHINGS M. J., 1986. Plant population biology. In: Moore P. D. and Chapman S. B. (eds), *Methods in Plant Ecology*, Blackwell Scientific Publications, Oxford, pp. 377-435.

HUTCHINGS, A., HAXTON SCOTT, A., LEWIS, G. and CUNNINGHAM, A., 1996. Zulu Medicinal Plants. An Inventory. University of Natal Press, Pietermaritzburg in association with University of Zululand, Kwblangezwa and National Botanical Institute, Cape Town.

HUTCHINSON, J. and DALZIEL, J. M., 1954- 1958. Flora of west tropical Africa. 2nd edn, Vol. 1. Crown Agents, London. 828 pp.

HUXLEY, P.A., 1996. Biological factors affecting form and function in woody–non-woody plant mixtures. *In,* Ong, C.K. and Huxley, P. (Eds.). *Tree–crop Interactions: A Physiological Approach.* CAB International, Wallingford, Oxford, UK, pp. 235–298.

ICRAF, 2002. Vegetative tree propagation in agroforestry trees: Training guidelines and references. *In,* Jaenicke, H. and Beniest, J., (Eds.). International Centre for Research in Agroforestry, Nairobi, Kenya. 140 pp.

ICRAF, 2005. *Sclerocarya birrea* (A. Rich.) Hochst. Agroforestree Database. http://intranet/icraf_web/sites/treebs/AFT/Speciesinfo.cfm?SpID=1513 5/7/2007, 5 pp.

IDDI S. 1998. Eastern arc mountains and their national global importance. *Journal of East African natural history*, **87** pp. 19 – 26.

IMMELMAN, W.F.E., WICHT, C.L. and ACKERMAN, P.P., 1973. Our Green Heritage. A book about indigenous and exotic trees in South Africa, about trees and timber in our cultural history and about our extensive silvicultural and timber industries. Tafel, Cape Town.

IRELAND, C., 1999. An economic valuation of crop production in Manganeng and Makua in the Northern Province of South Africa. MSc Thesis, Imperial College of Science, Technology and Medicine, University of London.

IWALEWA, E.O., MCGAW L.J., NAIDOO, V., ELOFF, J.N., 2007. Inflammation: The foundation of diseases and disorders. A review of phytomedicines of South African origin used to treat pain and inflammatory conditions. *African Journal of Biotechnology* **6**, pp. 2868-2885.

JACOBS, O. and BIGGS, R., 2002. The status and population structure of the marula in the Kruger National Park. *S. Afr. J. Wildl. Res.* **32** (2002), pp. 13–22.

JAENICKE, H. and THIONG'O, M.K., 2000. Preliminary nutritional analysis of marula *(Sclerocarya birrea)* fruits from two Kenyan provenances. Acta Horticulturae, **531**, pp. 245-249.

JAENICKE, H., SIMONS, A., MAGHEMBE, J. and WEBER, J., 2001. Domesticating indigenous fruit trees for agroforestry. *Acta Hort.* **523**, pp. 45-51.

JAMA, B.A., MOHAMED, A.M., MULATYA, J. and NJUI, A.N., 2008. Comparing the "Big Five": A framework for the sustainable management of indigenous fruit trees in the drylands of East and Central Africa. *Ecological Indicators,* **8**(2), pp. 170-179.

JANICK, J and PAULL, R; (editors) 2008. The Encyclopedia of Fruits and Nuts. CABI, Cambridge Massachussetes, 976 pp

JANZEN, D. and VAZQUEZ-YANES, C., 1991. Aspects of tropical seed ecology of relevance to management of tropical forested wildlands. *In,* Gomez-Pompa, A., Whitmore, T. C. and Hadley, M. (Eds). Rain forest regeneration and management. MAB Volume 6, UNESCO, Paris. pp. 137-154.

JENKINS, M.D. 1987., Madagascar. An Environmental Profile. IUCN. Gland, Switzerland and Cambridge, U.K.

JING, J., HONG, J., SHUQUAN, Y. and GUOMO, Z., 2008. Sex-linked photosynthetic physiologic research and the evolutionary ecological analysis in living fossil plant, Ginkgo biloba L. *Acta Ecologica Sinica,* **28**(3), pp. 1128-1136.

JOHNSON, D. and JOHNSON, S., 1993. Gardening with indigenous trees and shrubs. Southern Book Publishers. Halfway House. 182 pp.

JOHNSON, S., 1992. Climatic and phylogenetic determinants of flowering seasonality in the Cape Flora. *Journal of Ecology,* **81,** pp. 567–572.

JØKER, D. and ERDEY, D., 2003. *Sclerocarya birrea* (A. Rich.) Hochst. Seed leaflet no. 72, Danida Forest Seed Center, Humleback, Denmark and University of Natal, Natal, South Africa.

JOSHI, R., SHEKHAWAT, N. S. and RATHORE, T. S., 1991. Micropropagation of *Anogeissus pendula* Edgew - An arid forest tree. *Indian J. Exp. Biol.* **29**, pp. 615-618.

JUDD, W.S., CAMPBELL, C.S., KELLOGG, E.A. and STEVENS, P.F., 1999. Plant systematics: a phylogenetic approach. Sinauer, Sunderland. 464 pp

KADU, C.A.C., IMBUGA, M., JAMNADASS, R. and DAWSON, I.K., 2006. Genetic management of indigenous fruit trees in southern Africa: A case study of *Sclerocarya birrea* based on nuclear and chloroplast variation. *South African Journal of Botany,* **72**(3), pp. 421-427.

KADZERE, I., 2000. The status of *Sclerocarya birrea* in Zimbabwe. *In* Youde, E. (ed). A workshop to plan the production of a definitive species monograph on *Sclerocarya birrea* and associated extension literature. 13- 14th March 2000. Monographs and extension materials on *Sclerocarya birrea.* DFID FRP Project R7227. School of Agricultural and Forest Sciences, University of Wales, Bangor.

KADZERE, I., CHILANGA, T., RAMADHANI, T., LUNGU, S., MALEMBO, L., RUKUNI, D., SIMWANZA, P., RARIEYA, M. and MAGEMBE, J., 1998. Choice of priority indigenous fruit for domestication in Southern Africa. Summary of case studies in Malawi, Tanzania, Zambia and Zimbabwe. ICRAF Nairobi.

KAJEMBE, G., GERALD, C., MONELA, G. and MVENA, Z., 2003. Making community-based forest management work: A case study of Duru-Haitemba village forest reserve, Babati, Tanzania. *In,* Kowero, G., Campbell, B. M. and Ussif R. S. (Eds.). Policies and Governance Structures in Woodlands of Southern Africa. Centre for International Forestry Research (CIFOR), Bagor, Indonesia. 224 pp.

KARIN, G. and NONTOKOZO, N., 2006. Participatory Planting and Management of Indigenous Trees: Lessons from Chivi District, Zimbabwe. *Agriculture and Human Values* **23**, pp. 231 – 243.

KAYE, T., PENDERGRASS, K., FINLEY, K. and KAUFFMAN, J., 2001. The effect of fire on the population viability of an endangered prairie plant. *Ecological Applications* **11**, pp. 1366– 1380.

KERSTETTER, R.A. and HAKE, S., 1997. Shoot meristem formation in vegetative development. *Plant Cell,* **9**, pp. 1001-1010.

KHAN, M.R. and NKANYA, M.H.H., 1990. Antimicrobial activity of Tanzanian traditional medicinal plants. In: Ministry of Health. Proceedings of an International Conference on Traditional Medicinal Plants. Arusha, Tanzania, Feb 18 –13. Dar es Salaam University Press, Dar es Salaam.

KHONJE, C., NGULUBE, M.R. and CHANYEGA, T., 1999. Distribution and population structures of *Sclerocarya birrea* (A.Rich.) Hochst. Malawi. Forest Research Institute Malawi, Zomba, 22 pp.

KIKULA, I.S., 1986. The Influence of Fire on the Composition of Miombo Woodland of SW Tanzania. *Oikos,* **46**(3), pp. pp. 317-324.

KIMONDO, J., 2010. The potential for optimization of *Vitex payos* as a dryland resource in Kenya. PhD Thesis, Bangor University, UK.

KITAJIMA, K. and FENNER, M., 2000. Ecology of seedling regeneration. *In* Fenner, M. (Ed.). Seeds: The ecology of regeneration in plant communities. CAB International, Wallingford, UK. pp. 331-359.

KLEIMAN, R., ASHLEY, D.A. and BROWN, J.H., 2008. Comparison of two seed oils used in cosmetics, moringa and marula. *Industrial Crops and Products,* **28**(3), pp. 361-364.

KOCHMER, J. and HANDEL, S., 1986. Constraints and competition in the evolution of flowering phenology. *Ecological Monographs,* **56**, pp. 303-325.

KOKWARO, J.O. and GILLETT, J.B., 1980. Notes on the Anacardiaceae of Eastern Africa. *Kew Bulletin,* **34**(4), pp. 745-760.

KOKWARO, J.O., 1986. Flora of tropical east Africa: Anacardiaceae. Balkema, Amsterdam. 59 pp

KOKWARO, J.O., 1993. Medicinal plants of E. Africa. Second Ed. Kenya Literature Bureau.

KOUAKOU, K.L., BI, I.A.Z., ABESSIKA, Y.G., KOUAKOU, T.H. and BAUDOIN, J., 2009. Rapid seedlings regeneration from seeds and vegetative propagation with sucker and rhizome of Eremospatha macrocarpa (Mann & Wendl.) Wendl and Laccosperma secundiflorum (P. Beauv.) Kuntze. *Scientia Horticulturae,* **120**(2), pp. 257-263.

KOWERO, G., 2003. The challenge to natural forest management in Sub-Saharan Africa rural development: Experiences from the miombo woodlands of Southern Africa. *In,* Kowero, G., Campbell, B. M. and Ussif R. S. (Eds.). Policies and Governance Structures in Woodlands of Southern Africa. Centre for International Forestry Research (CIFOR), Bogor, Indonesia. 224 pp.

KOWERO, G.S. and SPILSBURY, M.J., 1997. *Capacity for forestry research in the Southern African Development Community.* Bogor, Indonesia: Center for International Forestry Research.

KRIGE, E. J., 1937. Notes on the Phalaborwa and their morula complex. *Bantu Studies,* **11,** pp. 357- 366.

KUNIN, W. E., 1993. Sex and the single mustard: population density and pollinator behavior effects on seed-set. *Ecology*, **74,** pp. 2145–2160.

KUSILUKA, M.M., KONGELA, S., KUSILUKA, M.A., KARIMURIBO, E.D. and KUSILUKA, L.J.M., 2011. The negative impact of land acquisition on indigenous communities' livelihood and environment in Tanzania. *Habitat International,* **35**(1), pp. 66-73.

KWESIGA, F., AKINNIFESI, F., RAMADHANI, T., KADZERE, I., SAKA, J., 2000. Domestication of indigenous fruit trees of the miombo in southern Africa. In: Shumba, E.M., Lusepani, E., Hangulai, H. (Eds.), The domestication and commercialization of indigenous fruit trees in the SADC region. SADC Tree Seed Centre Network, pp. 8–24.

LAMB, E., BAYNE, E., HOLLOWAY, G., SCHIECK, J., BOUTIN, S., HERBERS, J., HAUGHLAND, D., 2009. Indices for monitoring biodiversity change: are some more effective than others? Ecol. Indic. 9, pp. 432–444.

LARSON, A.M., 2010. Making the 'rules of the game': Constituting territory and authority in Nicaragua's indigenous communities. *Land Use Policy*, **27**(4), pp. 1143-1152.

LAWES, G., WOOLEY, D. and LAI, R., 1990. Seeds and other factors affecting fruit size in kiwifruit. *Acta Horticulturae,* **282**, pp. 257- 264.

LEAKEY, R.R.B. and NEWTON A.C., (eds.) 1994. *Domestication of timber and non-timber forest products.* MAB Digest 17. UNESCO, Paris. 94 p.

LEAKEY, R.R.B. and SIMONS, A.J., 1998. The domestication and commercialisation of indigenous trees in agroforestry for the alleviation of poverty. *Agroforestry Systems,* **38,** pp. 165-176.

LEAKEY, R. R. B., 1999. Potential for novel food products from agroforestry trees: A review. *Food-Chemistry.* **66** (1) pp.1-14.

LEAKEY, R., 1985. The capacity for vegetative propagation in trees. *In,* Cannell, M. and Jackson, J. (Eds.). Attributes of Trees as Crop Plants. Institute of Terrestrial Ecology, Monks Wood, UK. pp. 110-133.

LEAKEY, R., FONDOUN, J.M., ATANGANA, A. and TCHOUNDJEU, Z., 2000. Quantitative descriptors for variation in the fruit and seeds of *Irvingia gabonensis. Agroforestry Systems*, **50**, pp. 47–58.

LEAKEY, R., MESEN, J., TCHOUNDJEU, Z., LONGMAN, K., MCP. DICK, J., NEWTON, A., MATIN, A., GRACE, J., MUNRO, R. and MUTHOKA, P., 1990. Low-technology techniques for the vegetative propagation of tropical trees. *Commonwealth Forestry Revie,* **69**, pp. 247-257.

LEAKEY, R., NEWTON, A. and DICK, J., 1994. Capture of genetic variation by vegetative propagation: processes determining success. *In,* Leakey, R.R.B., Newton, A.C. (Eds.). *Tropical Trees: Potential for Domestication, Rebuilding Genetic Resources*. HMSO, London, UK, pp. 72-83.

LEAKEY, R., SHACKLETON, S. and PLESSIS, P.D., 2005. Domestication potential of Marula (*Sclerocarya birrea* subsp *caffra*)in South Africa and Namibia: 1. Phenotypic variation in fruit traits *Agroforestry Systems,* **64**(1), pp. 25-35.

LEAKEY, R.R.B. and NEWTON, A.C., 1994. Tropical Trees: The Potential for Domestication and the Rebuilding of Forest Resources. HMSO, London, UK, p. 284.

LEAKEY, R.R.B. and AKINNIFESI, F. K., 2008. Towards a domestication strategy for indigenous fruit trees: Clonal propagation, selection and the conservation and use of genetic resources. *In* Akinnifesi FK, Leakey RRB, Ajayi OC, Sileshi G, Tchoundjeu Z, Matakala P, Kwesiga FR (Eds). *Indigenous Fruit Trees in the Tropics: Domestication, Utilization and Commercialization.* World Agroforestry Centre: Nairobi. CAB, Wallingford.

LEAKEY, R.R.B. and SIMONS, A.J., 2000. When does vegetative propagation provide a viable alternative to propagation by seed in forestry and agroforestry in the tropics and sub-Tropics. *In* Wolf, H. and Albrecht J. (Eds.). The Procurement of Forestry Seeds in Tropical and Subtropical Countries - The Example of Kenya Contributions to Forest Sciences. Verlag, India, pp: 67-81.

LEAKEY, R.R.B. and TCHOUNDJEU, Z., 2001. Diversification of tree crops: Domestication of companion crops for poverty reduction and environmental services. *Experimental Agriculture*, **37**, pp. 279-296.

LEAKEY, R.R.B. and TOMICH, T.P. 1999. Domestication of tropical trees: from biology to economics and policy. *In* Buck, L.E., Lassoie, J.P. and Fernandes, E.C.M. (Eds.). *Agroforestry in sustainable agricultural systems*. pp 319-338. CRC Press/Lewis Publishers, New York.

LEHMANN, C.E.R., RATNAM, J. and HUTLEY, L.B., 2009. Which of these continents is not like the other? Comparisons of tropical savanna systems: key questions and challenges. *New Phytologist*, **181**, pp. 508–511.

LEISHMAN, M. R., WESTOBY, M. and JURADO, E., 1995. Correlates of seed size variation: a comparison among 5 temperate floras. *Journal of Ecology,* **83**, pp. 517 – 529.

LEOPOLD, A., 1951. Photoperiodism in plants. *Quarterly Review of Biology*, **26,** pp. 247-263.

LESSARD, C., REED, D. and MONKEVICH, N., 1994. Comparing n-tree distance sampling with point and plot sampling in northern Michigan forest types. *N J Appl For* **11**, pp. 12–16.

LEWIS, D.M. 1987. Fruiting patterns, seed germination, and distribution of *Sclerocarya caffra* in an elephant-inhabited woodland. *Biotropica*, **19**, pp. 50-56.

LIENGME, C.A., 1981. Plants used by the Tsonga people of Gazankulu. *Bothalia*, **13**, pp. 501 – 518.

LIETH, H., 1974. *Phenology and seasonality modeling. Ecological Studies*. Springer-Verlag, Berlin. 444 pp.

LINDISTRÖM, J. and KINGAMKONO R. 1991. Nutrition and food security roles of gathered food and livestock keeping in two villages in Babati District, Northern Tanzania. Foods from forests, fields and fallows. Swedish University of agricultural Sciences, international rural development centre in collaboration with Tanzania food and nutrition centre (TFNC). Working paper 184 Uppsala.

LOBO, J., QUESADA, M., STONER, K., FUCHS, E., HERRERI'AS-DIEGO, Y., ROJAS, J., SABORI'O, G., 2003. Factors affecting phenological patterns of bombacaceous trees in seasonal forests in Costa Rica and Mexico. *American Journal of Botany*, **90**, pp.1054–1063.

LOMBARD, C. ALLANIC, B. and SHILOTE, B., 2000. Potential for the development of marula products in the Bushbuckridge area. DANCED – Community Forestry Project in the Bushbuckridge area, Department of Water Affairs and Forestry, Nelspruit. 71 pp.

LOMBARD, C., ALLANIC, B. and SHILOTE, B., 2000. Potential for the development of marula products in the Bushbuckridge area. DANCED – Community Forestry Project in the Bushbuckridge area. Department of Water Affairs and Forestry, Nelspruit. 71 pp.

LONGMAN, K.A., 1993. *Rooting Cuttings of Tropical Trees.* Tropical Trees: Propagation and Planting Materials, Vol. 1. London. Commonwealth Science Council.

LOUBRY , D., 1994 . D é terminisme du comportement ph é nologique des arbres en f ô ret tropicale humide de Guyane Fran ç aise (5 ° lat. N), Paris. Ph.D. thesis, Universit é de Paris VI, Paris, France.

LOVELL, P. H. and WHITE, J., 1986. Anatomical changes during adventitious root formation. *In,* Jackson, M.B. (Ed.). New Root Formation in Plants and Cuttings. Martinus Nijhoff Publishers, Dordrecht, The Netherlands. pp. 111-140.

LUDWIG, J. A. And REYNOLDS, J. F., 1988. Statistical ecology. USA: John Wiley & Sons.

MABBERLEY, D.J., 1997. The plant book, 2nd edn. Cambridge University Press, Cambridge. 858 pp

MADDOX, G., 2006. *Sub-Saharan Africa: An environmental history.* Santa Barbara, Calif.: Abc-Clio.

MAGHEMBE, J. and SEYANI, J., 1992. Multipurpose trees used by smallscale farmers in Malawi: results of an ethnobotanical survey. AFRENA Report No. 42. International Centre for Research in Agroforestry, Nairobi, Kenya.

MAGHEMBE, J.A., KWESIGA, F., NGULUBE, M., PRINS, H. and MALAYA, F.M., 1994. Domestication potential of indigenous fruit trees of the Miombo woodlands of southern Africa. *In* Leakey, R.R.B. and Newton, A.C. (Eds). Tropical trees: the potential for domestication and the rebuilding of forest resources. pp. 220-229.

MAGIGI, W. and DRESCHER, A.W., 2010. The dynamics of land use change and tenure systems in Sub-Saharan Africa cities; learning from Himo community protest, conflict and interest in urban planning practice in Tanzania. *Habitat International,* **34**(2), pp. 154-164.

MAIGNAN, F., BREON, F. M., BACOUR, C., DEMARTY, J. and POIRSON, A., 2008. Interannual vegetation phenology estimates from global AVHRR measurements: Comparison with in situ data and applications. *Remote Sensing of Environment*, **112**, pp. 496–505.

MAKOM, N. I., FRIGERIO, F., CASIMIR, M., NGUEGUIM, T. F., DONGO, E., KAMTCHOUING, P., DIMO, T. and MAECHLER P., 2010. *Sclerocarya birrea* (Anacardiaceae) stem-bark extract corrects glycaemia in diabetic rats and acts on beta-cells by enhancing glucose-stimulated insulin secretion. *Journal of Endocrinology,* **205**(1), pp. 79-86.

MALAISSE, F. and PARENT, G., 1985. Edible wild vegetable products in the Zambezian woodland area: A nutritional and ecological approach. *Ecology of Food and Nutrition,* **18**, pp. 43-82.

MALAISSE, F., 1978. The Miombo ecosystem. In Tropical forest ecosystems: A state of knowledge report, pp. 589-606. UNESCO, Paris.

MANDAL, A., PATRA, A.K., SINGH, D., SWARUP, A. and EBHIN MASTO, R., 2007. Effect of long-term application of manure and fertilizer on biological and biochemical activities in soil during crop development stages. *Bioresource technology,* **98**(18), pp. 3585-3592.

MAPAURE, I.N. and CAMPBELL, B.M., 2002. Changes in miombo woodland cover in and around Sengwa Wildlife Research Area, Zimbabwe, in relation to elephants and fire. *African Journal of Ecology,* **40**(3), pp. 212-219.

MARCHAL, J.Y. 1980. Arbres et brousses de paysage soudano-sahélien; dynamiques des formations végétales au nord de la Haute Volta. Cahiers de l'Office de la Recherche Scientifique et Technique Outre-Mer, *Série Science Humaine,* **17**, pp. 137-149.

MARCHAND, N. L., 1869. Révision du groupe des Anacardiacées. Ballière, Paris. 198 pp.

MARUZANE, D., TAPFUMANEYI, L. and MATARIRANO, L.C., 2002. Marula propagation, uses and marketing. World Agroforestry Centre, Kenya. 22 pp.

MATEKE, S., 2000. Cultivation of native fruit trees of Kalahari sandveld: studies on the commercial potential, interactions between soil and biota in Kalahari sands of southern Africa. Project Report. Velds Product, Botswana, p. 49.

MATEKE, S.M. and TSHIKAE, P.B., 2002. Selection and cultivation of Kalahari native edible fruit producing trees: Botswana's eight years experience. Paper presented at the Southern Africa Agroforestry Conference, 20- 24 May 2002, Warmbaths, South Africa, 29 pp.

MATHABE, M.C., NIKOLOVA, R.V., LALL, N., and NYAZEMA, N.Z., 2006. Antibacterial activities of medicinal plants used for the treatment of diarrhoea in Limpopo Province, South Africa. *Journal of Ethnopharmacology* **105**, pp. 286–293.

MATHER, K., 1947. *Statistical analysis in biology.* In-terscience Publishers, Inc., New York.

MAUNDU, P.M., NGUGI, G.M. and KABUYE, C.H.S., 1999. Traditional food plants of Kenya. Kenya Regional Resource Centre for Indigenous Knowledge/National Museums of Kenya, Nairobi. 270 pp.

MBUYA, L. P., MSANGA, H. P., RUFFO, C. K., BIRNE, A. and TENGNAS B.O., 1994. Useful trees and shrubs in Tanzania. Identification, propagation and management for agricultural and pastoral communities. Nairobi. Regional Soil Conservation Unit (RSCU). Swedish International Development Authority (SIDA). Technical Handbook Series 6. Regal Press Ltd.

McGREGOR, J., 1995. Gathered produce in Zimbabwe's communal areas. Changing resource availability and use. *Ecology of Food and Nutrition* **33**, pp.161 –193.

McHARDY, T., 2002. Inventory of available marula resources on the Makhatini Flats Maputaland in the fruiting season of 2002. Report to UK DFID Forestry Research Programme (Project No R7795). Institute of Natural Resources, Scottsville, South Africa.

MENCUCCINI, M., MARTINEZ-VILALTA, J., HAMID, H.A., KORAKAKI, E. and VANDERKLEIN, D., 2007. Evidence for age and size mediated controls of tree growth from grafting studies. *Tree Physiol.* **27**, pp. 463–473.

MHANGO, J., AKINNIFESI, F.K., 2001. On-farm assessment of farmer management and perception of priority indigenous fruit trees in southern Malawi. In: Proceedings of the 14th Southern Africa Regional Review and Planning Workshop, Harare, Zimbabwe.

MILIMO, B., 1994. The chemical composition of Melia volkensii Gurke: an unrealised browse potential for semi-arid agroforestry. *Journal of the Science of Food and Agriculture,* **64** (3), pp. 365-370.

MISANA, S., MUNG'ONG'O, C., MUKAMURI, B., 1996. Miombo woodlands in the wider context: macro-economic and inter-sectoral influences. *In* Campbell, B. (Ed.), The Miombo in Transition: Woodlands and Welfare in Africa. Centre for International Forestry Research, Bogor, Indonesia, pp. 73–99.

MNG'OMBA, S., AKINNIFESI, F., SILESHI, G., AJAYI, O., CHAKEREDZA, S., MWASE, F., 2008. A decision support tool for propagating Miombo indigenous fruit trees of southern Africa. *African Journal of Biotechnology* **7** (25), pp. 4677- 4686.

MNRT, 2002. The New Forest Act. no.14 of 7th June 2002. Ministry of Natural Resources and Tourism. The United Republic of Tanzania. Government Printer. Dar es Salaam. Tanzania. 174 p.

MNRT., 1998. National Forestry policy. Ministry of Natural Resources and Tourism. United Republic of Tanzania. 59p.

MNRT., 1999. National Tourism Policy. Ministry of Natural Resources and Tourism. Government Printers, Dar es Salaam, United Republic of Tanzania.

MOGANEDI, K., SIBARA, M., GROBLER, P and GOYVAERTS, E., 2011. An assessment of genetic diversity among *marula* populations using the amplified fragment length polymorphism (AFLP) technique. *African Journal of Agricultural Research,* **6**(4), pp. 790-797

MOJEREMANE, W. and TSHWENYANE, S.O., 2004. *Azanza garckeana*: A valuable Edible Indigenous Fruit tree of Botswana. *Pak. J. Nutr.*, **3**, pp. 264-267.

MOLAU, U., NORDENHALL, U. and ERIKSEN, B., 2005. Onset of flowering and climate variability in an alpine landscape: A 10-year study from Swedish Lapland. *American Journal of Botany*, **92**, pp. 422–431.

MONTESINOS, D., GARCÍA-FAYOS, P. and VERDÚ, M., 2010. Relictual distribution reaches the top: Elevation constrains fertility and leaf longevity in Juniperus thurifera. *Acta Oecologica,* **36**(1), pp. 120-125.

MORISON, C.G.T., HOYLE, A.C. and HOPE-SIMPSON, J.F., 1948. Tropical soil vegetation catenas and mosaics. *Journal of Ecology*, **36**, pp. 1-84.

MORRIS, B., 1996. Chewa medical botany. A study of herbalism in Southern Malawi. International African Institute, London.

MOSQUIN, T., 1971. Competition for pollinators as a stimulus for the evolution of flowering time. Oikos, 22, pp. 398 – 402.

MOYO, M., FINNIE, J.F. and VAN STADEN, J., Antimicrobial and cyclooxygenase enzyme inhibitory activities of *Sclerocarya birrea* and Harpephyllum caffrum (Anacardiaceae) plant extracts. *South African Journal of Botany*, **In Press, Corrected Proof**

MOYO, M., FINNIE, J.F. and VAN STADEN, J., 2009. In vitro morphogenesis of organogenic nodules derived from *Sclerocarya birrea* subsp. *caffra* leaf explants. *Plant Cell Tissue Org. Cult.*, **98**, pp. 273–280.

MOYO, M., NDHLALA, A.R., FINNIE, J.F. and VAN STADEN, J., 2010. Phenolic composition, antioxidant and acetylcholinesterase inhibitory activities of *Sclerocarya birrea* and Harpephyllum caffrum (Anacardiaceae) extracts. *Food Chemistry,* **123**(1), pp. 69-76.

MSANGA, H.P., 1998. *Seed Germination of Indigenous Trees in Tanzania*, Including Notes on Seed processing, Storage, and Plant Uses. BC Press, Vancouver, Canada. 292 pp

MSHANA N. R., ABBIW D. K., ADDAE-MENSAH, I., ADJANOUHOUN, E., AHYI, M. R. A., EKPERE, J. A., ENOW-OROCK, E. G., GBILE, Z. O., NOAMESI, G. K., ODEI, M. A., ODUNLAMI, H., OTENG-YEBOAH, A. A., SARPONG, K., SOFOWORA, A., and TACKIE, A. N., 2000. Traditional Medicine and Pharmacopoea contribution to the revision of Ethnobotanical and Floristic Studies in Ghana. 2nd Edition, Publication of the Scientific, Technical and Research Commission of the Organization of Africa Unity (OAU/STRC).

MUGASHA, A.G., 1978. Tanzania natural forest silviculture research review report. Tanzania silviculture technical note (new series) no. 39. Forestry Division, Ministry of Natural Resources and Tourism. Dar es salaam.

MULLENDERS, W., 1954. La végétation de Kaniama. *Publications de l'Institut National pour l'Étude Agronomique du Congo Belge, Série Scientifique*, **61**, pp. 1- 499.

MUNJUGA, M. R., 2000. *Sclerocarya birrea* subspecies *birrea* (A.Rich.) Hochst.: a reproductive biology. International Centre for Research in Agroforestry, Nairobi. 14 pp.

MUOK, B.O., MATSUMURA, A., ISHII, T. and ODEE, D.W., 2007. Genetic diversity within *Sclerocarya birrea* populations in Kenya. *Journal of Arid Environments,* **71**(1), pp. 1-11.

MURALI, K.S. and SUKUMAR, R., 1994. Reproductive phenology of a tropical dry forest in Mudumalai, Southern India. *Journal of Ecology,* **82**, pp. 759–767.

MURRAY, B. and GILL, A., 2001. A comparative study of interspecific variation in fruit size among Australian eucalypts. *Ecography,* **24**, pp. 651–658.

MUTO, M. and YAMANO, T., 2009. The Impact of Mobile Phone Coverage Expansion on Market Participation: Panel Data Evidence from Uganda. *World Development,* **37**(12), pp. 1887-1896.

MWANG'INGO, P.L.P., 2002. Ecology and silviculture of *Osyris lanceolata* (African sandalwood): An aromatic tree of Tanzania. PhD Thesis. School of Agriculture and Forest Sciences, University of Wales Bangor, United Kingdom. 263 p.

NAYAK, K.G. and DAVIDAR, P., 2010. Pollination and breeding systems of woody plant species in tropical dry evergreen forests, southern India. *Flora - Morphology, Distribution, Functional Ecology of Plants,* **205**(11), pp. 745-753.

NDABIKUNZE, B.K; CHAMSHAMA, S.A.O.; TIISEEKWA, B.P.M. and MUGASHA, A.G. 2000. Nutrition and utilization of indigenous tree food sources in Tanzania. Proceedings of SADC tree seed centre network technical meeting held in Windhoek, Namibia 13 - 14 March 2000.

NDANGALASI, H.J., BITARIHO, R. and DOVIE, D.B.K., 2007. Harvesting of non-timber forest products and implications for conservation in two montane forests of East Africa. *Biological Conservation,* **134**(2), pp. 242-250.

NEMUDZUDZANYI, A.O., ZOBOLO, A.M. , SIEBERT, S.J., 2009. A comparative floristic analysis of peri-urban and rural homegardens in Zululand, South Africa. Annual Conference of the South African Association of Botanists (SAAB) and International workshop on Phosphate as a limiting resource. Stellenbosch University, 19 –22nd Jan 2009. Available online on 12/5/2009 at http://academic.sun.ac.za/botzoo/saab2009/SAAB_2009_Abstract_Book-final.pdf

NERD, A. and MIZRAHI, Y., 1993. Domestication and introduction of marula (*Sclerocarya birrea* subsp. *caffra*) as a new crop for the Negev desert of Israel. *In* Janick, J. and Simon, J.E. (Eds.). *New crop,* pp. 496 - 499. Wiley, New York.

NEUMANN, K., KAHLHEBER, S. and UEBEL, D., 1998. Remains of woody plants from Saouga, a medieval west African village. *Vegetation History and Archaeobotany*, **7**, pp. 57- 77.

NGHITOOLWA, E., HALL, J.B. and SINCLAIR, F.L., 2003. Population status and gender imbalance of the marula tree, *Sclerocarya birrea* subsp. *caffra* in northern Namibia *Agroforestry Systems,* **59**(3), pp. 289-294.

NGULUBE, M., 2000. Status of *Sclerocarya birrea* in Malawi. *In* Youde, E. (ed). Monographs and extension materials on *Sclerocarya birrea.* A workshop to plan the production of a definitive species monograph on *Sclerocarya birrea* and associated extension literature. 13- 14 March, 2000. DFID FRP Project R7227. School of Agricultural and Forest Sciences, University of Wales, Bangor.

NIKIEMA, A., SANON, M.D., FRAITURE, A. and TOLKAMP, G.W., 1993. Fiches de production de plantes en pépinière. Centre National de Semences Forestière, Ouagadougou, *Note Technique*, **4**, pp. 1-91.

NKETIAH, T., NEWTON, A.C. and LEAKEY, R.R.B., 1998. Vegetative propagation of *Triplochiton scleroxylon* K. Schum in Ghana. *Forest Ecology and Management,* **105**(1-3), pp. 99-105.

NORRIS, K., ASASE, A., COLLEN, B., GOCKOWKSI, J., MASON, J., PHALAN, B. and WADE, A., 2010. Biodiversity in a forest-agriculture mosaic – The changing face of West African rainforests. *Biological Conservation,* **143**(10), pp. 2341-2350.

OBESO, J.R., 2002. The costs of reproduction in plants. *New Phytologist,* **155**(3), pp. 321-348.

O'BRIEN, SEAN T., STEPHEN P. HUBBELL, PETER SPIRO, RICHARD CONDIT, and ROBIN B. FOSTER. (1995). Diameter, Height, Crown, and Age Relationship in Eight Neotropical Tree Species. *Ecology* (76):1926–1939

OGBOBE, O., 1992. Physicochemical composition and characterization of the seed and seed oil of *Sclerocarya birrea. Plant Foods for Human Nutrition*, **42**, pp. 201-206.

OHLER, F.M.J., 1985. The fuelwood production of wooded savanna fallows in the Sudan zone of Mali. Agroforestry Systems, **3**: 15-23

OJEWOLE, J.A., 2003. Hypoglycemic effect of *Sclerocarya birrea* [(A. Rich)] Hochst [Anacardiaceae] stem bark aqueous extract in rats. *Phytomedicine,* **10**, pp. 675–681.

OKAFOR, J.C. and LAMB, A. 1994. Fruit trees: Diversity and conservation strategies. *In*, Leakey, R.R.B. and Newton, A. (Eds.). *Tropical trees: potential for domestication, rebuilding genetic resources*. HMSO, London.

Okia, A.C., 2010. *Balanites egyptiaca*: A resource for improving nutrition and income of dryland communities in Uganda. PhD Thesis, Bangor University, UK

OPLER, P., FRANKIE, G. and BAKER, H., 1976. Rainfall as a factor in the release, timing, and synchronization of anthesis by tropical trees and shrubs. *Journal of Biogeography* **3,** pp. 231-236.

ORONU, L.O.N., MUGASHA, A.G. and CHAMSHANA S.A.O., 1998. Effect of seed pre-treatment on germination of *Vitex doniana* seed. *In* Malimbwi, R.E. and Nsolomo, V.R. (Eds). Proceedings of SUA/AUN workshop on Tanzania Forestry sector: Problems and possible solutions. March 23rd to 26th 1998, Olmotony Arusha, Tanzania.

OSADA, N., TATENO, R., HYODO, F., TAKEDA, H., 2004. Changes in crown architecture with tree height in two deciduous tree species: developmental constraints or plastic response to the competition for light? *Forest Ecology and Management*, **188**, pp. 337–347.

ÖSTERGÅRD, H. and EHRLÉN, J., 2005. Among population variation in specialist and generalist seed predation: the importance of host plant distribution, alternative hosts and environmental variation. *Oikos*, **111**, pp. 39 – 46.

OSTROM, E. (2009a). A Polycentric Approach for Coping with Climate Change (October 1, 2009). World Bank Policy Research Working Paper Series, Vol. , pp. -, 2009. Available at SSRN: http://ssrn.com/abstract=1494833

OSTROM, E. (2009b). A general framework for analyzing sustainability of social-ecological systems. Science 325(5939): 419-422.

PALMER, E. and PITMAN, N., 1961. Trees of South Africa. Balkema, Cape Town. 352 pp.

PALMER, E. and PITMAN, N., 1972-1974. *Trees of southern Africa* (3 vols). Balkema, Cape Town. 2235 pp.

PELL, S.K. and URBATSCH, L., 2000. Evaluation of evolutionary relationships in Anacardiaceae using matK sequence data. *American Journal of Botany,* **87**, pp. 149

PETERS, C. R., 1988. Notes on the distribution and relative abundance of *Sclerocarya birrea* (A.Rich.) Hochst. (Anacardiaceae). Monograph in Systematic Botany of the Missouri Botanical Garden **25**, pp. 403 -410.

PETERS, R., CLOUTIER, S., DUBE, D., EVENS, A., HASTINGS, P., KAISER, H., KOHN, D. and SARWER-FONER, B., 1988. The allometry of the weight of fruit on trees and shrubs in Barbados. *Oecologia* (Berlin) **74**, pp. 612-616.

PLACE, F., 2009. Land Tenure and Agricultural Productivity in Africa: A Comparative Analysis of the Economics Literature and Recent Policy Strategies and Reforms. *World Development,* **37**(8), pp. 1326-1336.

POOLEY, E. S., 1993. The complete guide to trees of Natal, Zululand and Transkei. Natal Flora Publications Trust, Durban. 512 pp.

POOLEY, E.S., 1980. Some notes on the utilisation of natural resources by the tribal people of Maputaland. *In* Bruton, M.N. a Cooper, K.H. (Eds.). Studies on the Ecology of Maputaland. Rhodes University and the Natal Branch of the Wildlife Society of Southern Africa, Grahamstown and Pietermarizburg.

POSEY, D.A., and DUTFIELD, G., 1996. Beyond intellectual property. Towards traditional resource rights for indigenous peoples and local communities. IDRC, Canada.

PRANCE, G.T., 1994. Amazonian tree diversity and the potential for supply of non-timber forest products, *In,* Leakey, R.R.B. and Newton, A.C., (Eds.). *Tropical Trees: The Potential for Domestication and the Rebuilding of Forest Resources*, pp. 7–15, HMSO, London, UK.

PRETORIUS, V., ROHWER, E., RAPP, A., HOLTZHAUSEN, L.C. and MANDERY, H. 1985. Volatile flavour components of marula (*Sclerocarya birrea* ssp. *caffra*) juice. Zeitschrift für Lebensmittel-Untersuchung und Forschung, **181**, pp. 458-461

QUIN, P.J., 1959. Food and feeding habits of the Pedi. University of the Witwatersrand Press, Johannesburg. South Africa. 278 pp.

RAMADHANI, T., CHILE, B. and SWAI, R., 1998. Indigenous Miombo fruits selected for domestication by farmers in Tanzania. In: Magembe, J., Simons, A., Kwesiga, F. and Rarieya, M. (Eds). Selecting indigenous trees for domestication in Southern Africa. Priority setting with farmers in Malawi, Tanzania, Zambia and Zimbabwe. ICRAF Nairobi.

RANDRIANASOLO, A., 2001. Taxonomic notes on Malagasy *Sclerocarya birrea* subspecies *caffra* (Sond.) Kokwaro. Missouri Botanical Garden, St Louis. 10 pp.

RATHEKE, B. and LACEY, E.P., 1985. Phenological patterns of terrestrial plants. *Annual Review of Ecology and Systematics*, **16**, pp. 179–214.

RAVIV, M. and REUVENI, O., 1984. Mode of leaf shedding from avocado cuttings and the effect of its delay on rooting. *HortScience*, **19**, pp. 529—531.

REICHP, B. and BORCHERT, R., 1984. Waters tress and tree phenology in a tropical dry forest in the lowlands of Costa Rica. *Journal of Ecology* **72**, pp. 61-74.

RIBEIRO, N., SAATCHI, S., SHUGART, H. and WASHINGTON-ALLEN, R., 2008. Aboveground biomass and leaf area index (LAI) mapping for Niassa Reserve, northern Mozambique. *J. Geophys. Res.–Biogeosci.* **113**, G02S02

RICHINGS, E.W., CRIPPS, R.F. and COWAN, A.K., 2000. Factors affecting 'Hass' avocado fruit size: carbohydrate, abscisic acid and isoprenoids metabolism in normal and phenotypically small fruit. *Physiologia Plantarum,* **109**, pp. 81-89.

RIVERA, G., ELLIOTT, S., CALDAS, L., NICOLOSSI, G., CORADIN, V. And BORCHERT, R., 2002. Increasing day-length induces spring flushing of tropical dry forest trees in the absence of rain. *Trees,* **16**, pp. 445-456.

ROACH, D. and WULFF, R., 1989. Maternal effects in plants. *Annual Review in Ecology and Systematics*, **18**, pp. 209–235.

ROM, R.C. and CARLSON, R.F., 1987. Apple rootstocks. *In*, Rootstocks for fruit crops. John Wiley and Sons, New York.

ROODT, V., 1988. The Shell field guide to the common trees of the Okavango Delta and Moremi Game Reserve. Shell, Gaborone.

RUBIN, B.D., MANION, P.D. and FABER-LANGENDOEN, D., 2006. Diameter distributions and structural sustainability in forests. *Forest Ecology and Management,* **222**(1-3), pp. 427-438.

RUFFO, K., BIRNIE, A. and TENGNÄS, B. 2002. *Edible wild plants of Tanzania.* Technical handbook No. 27. Regional Land Management Unit (RELMA).

RUGINI, E. and VERMA, D., 1983. Micropropagation of difficult to propagate almond *(P. Amygdalus* Batch.) cultivar. *Plant Sci. Lett.*, **28**, pp. 273-281.

RUGINI, E., JACOBONI, A. and LUPPINO, M., 1993. Role of basal shoot darkening and exogenous putrescine treatments on in vitro rooting and on endogenous polyamine changes in difficult-to-root woody species. *Scientia Horticulturae,* **53**(1-2), pp. 63-72.

RUNA, E.M., KRESS, W.J., 2002. Habitat fragmentation and the demographic structure of an Amazonian understory herb (Heliconia acuminata). *Conservation Biology* **16**, pp. 1256–1266.

SAKA, J.D.K., MWENDO-PHIRI, E. and AKINNIFESI, F.K., 2002. Community processing and nutritive value of some miombo indigenous fruits in central and southern Malawi. In: Kwesiga F, Ayuk E nd Agumya A (eds) Proceedings of the 14th Southern Africa Regional Review and Planning Workshop, 3-7 September 2001, Harare, Zimbabwe, pp 165 -169. ICRAF Regional Office, Harare, Zimbabwe.

SAKA, J.D.K., SWAI, R., MKAIDA, A., SCHORABURG A., KWESIGA, F. and AKINNIFESI, F.K., 2004. Processing and utilization of the indigenous miombo in Southern Africa. Agroforestry impacts livelihoods in Southern Africa: Putting Research into Practice pp 343 – 352 in Rao, M.R, Kwesiga, F.R. (eds) Proc. Regional Agroforestry conference Nairobi, Kenya.

SAKAI, S., MOMOSET, K., YUMOTO, T., NAGAMITSU, T., NAGAMASUA, H., HAMIDA, A. And NAKASIIIZUKA, T., 1999. Plant reproductive phenology over four years including an episode of general flowering in a lowland dipterocarp forest. Sarwak. Malaysia. *American Journal of Botany*, **86**, pp. 1414-1436.

SALINAS-PEBA, L. and PARRA-TABLA, V., 2007. Phenology and pollination of *Manilkara zapota* in forest and homegardens. *Forest Ecology and Management*, **248**, pp. 136–142.

SANOU, H., KAMBOU, S., TEKLEHAIMANOT, Z., DEMBÉLÉ, M., YOSSI, H., SIBIDU, S., DJINGDIA, L. and BOUVET, J., 2004. Vegetative propagation of *Vitellaria paradoxa* by grafting. *Agroforestry Systems*, ***60***, pp. 93-99.

SAVILLE, N. and UPADHAYA, S. N., 2006. Indigenous knowledge of beekeeping in Jumla, West Nepal. Available on line on 23/04/2010 at: http://www.beekeeping.com/articles/us/saville/indigenous_knowledge.htm.

SCHATZ, G.E., 2001. Generic tree flora of Madagascar. Royal Botanic Gardens, Kew. 477 pp.

SCHOLES, R.J. and WALKER, B.H., 1993. An African savanna: synthesis of the Nylsvley study. Cambridge University Press, Cambridge. 306 pp.

SCOONES, I., MELNYK, M. and PRETTY, J.N., 1992. *The Hidden Harvest: Wild Foods and Agricultural Systems: A Literature Review and Annotated Bibliography.* IIED, Swedish International Development Authority and World Wide Fund for Nature, London and Gland.

SEGHIERI, J., FLORET, C. and PONTANIER, R., 1995. Plant phenology in relation to water availability: herbaceous and woody species in the savannas of northern Cameroon. *Journal of Tropical Ecology,* **11**, pp. 237-254.

SELWYN , M and PARTHASARATHY, N., 2006. Reproductive traits and phenology of plants in tropical dry evergreen forest on the Coromandel coast of India. *Biodiversity and Conservation,* **15**, pp. 3207 – 3234.

SEPASAL database. 2001. *Sclerocarya birrea* (A. Rich.) Hochst. Subsp. *Caffra* (Sond.) Kokwaro. Royal Botanic Gardens, Kew. http://www.rbgkew.org.uk/ceb/sepasal/birrea.htm.

SEYMOUR, G., MANNING, K., ERIKSSON, E., POPOVICH, A., and KING G., 2002. Genetic identification and genomic organization of factors affecting fruit texture. *Journal of Experimental Botany*, **53**, pp. 2065–2071.

SHACKLETON, C.M., 1997. The prediction of woody productivity in the savanna biome, South Africa. PhD Dissertation, University of the Witwatersrand, Johannesburg, South Africa.

SHACKLETON, C. M., 1993. Demography and dynamics of the dominant woody species in a communal and protected area of the eastern Transvaal lowveld. *South African Journal of Botany* **59,** pp. 569-574.

SHACKLETON, C.M. and SCHOLES, R.J., 2000. Impact of fire frequency on woody community structure and soil nutrients in the Kruger National Park. *Koedoe,* **43**, pp. 75-81.

SHACKLETON, C.M. and SHACKLETON, S.E., 2000. Direct use values of secondary resources harvested from communal savannas in the Bushbuckridge lowveld, South Africa. *Journal of Tropical Forest Products* **6**, pp. 28 - 47.

SHACKLETON, C.M., 1996. Potential stimulation of local rural economies by harvesting secondary products: A case study of the central Transvaal lowveld, South Africa. *Ambio* **25**, pp. 33 - 38.

SHACKLETON, C.M., BOTHA, J. and EMANUEL, P.L., 2003. Productivity and abundance of *Sclerocarya birrea* subsp. *caffra* in and around rural settlements and protected areas of the Bushbuckridge lowveld, South Africa. *Forests, Trees Livelihood* **13**, pp. 217–232.

SHACKLETON, C.M., DZEREFOS, C.M., SHACKLETON, S.E. and MATHABELA, F.R., 2000. The use and trade in indigenous edible fruits in the Bushbuckridge savanna region, South Africa. *Ecology of Food and Nutrition*, **39**, pp. 225 – 245.

SHACKLETON, C.M., GUTHRIE, G., and MAIN, R., 2005. Estimating the potential role of commercial over-harvesting in resource viability: A case study of five useful tree species in South Africa. *Land Degrad. Dev.* **16**, pp. 273– 286.

SHACKLETON, S. E., SHACKELTON, C. M., CUNNINGHAM, A. B., LOMBARD, C., SULLIVAN, C. A., NETSHILUVHI, T. R., 2002. Knowledge on *Sclerocarya birrea* subsp. *caffra* with emphasis on its importance as a non-timber forest product in South and southern Africa: A summary. Part 1: Taxonomy, ecology and role in rural livelihoods. *South African Forestry Journal* **194**, pp. 27–41.

SHACKLETON, S., CAMPBELL, B., LOTZ-SISITKA, H. and SHACKLETON, C., 2008. Links between the Local Trade in Natural Products, Livelihoods and Poverty Alleviation in a Semi-arid Region of South Africa. *World Development,* **36**(3), pp. 505-526.

SHACKLETON, S., SULLIVAN, C., CUNNINGHAM, T., LEAKEY, R., LAIRD, S., LOMBARD, C., MANDER, M., NETSHILUVHI, T., SHACKLETON, C., and WYNBERG, R., 2003. An overview of current knowledge on *Sclerocarya birrea* (A. Rich.) Hochst. subsp. *caffra* (Sond.) Kokwaro with particular reference to its importance as a nontimber forest product (NTFP) in southern Africa. Winners and Losers in Forest Product Commercialisation: Marula Commercialisation for Sustainable Livelihoods. DFID project number ZF0140/R7795

SHACKLETON, S.E. and SHACKLETON, C.M., 2005. The contribution of marula fruits and fruit products to rural livelihoods in the Bushbuckridge district, South Africa: Balancing domestic needs and commercialisation. *Forest, Trees and Livelihood,* **15**, pp. 3–24.

SHACKLETON, S.E., SHACKLETON, C.M., and COUSINS, B., 2000. Re-valuing the communal lands of southern Africa: New understandings of rural livelihoods. ODI Natural Resource Perspectives (NRP) series, No 63.

SHACKLETON, S.E., STADLER, J.J., JEENES, K.A., POLLARD, S.R. and GEAR J.S.S., 1995. Adaptive strategies of the poor in arid and semi-arid lands – in search of sustainable livelihoods. A case study of the Bushbuckridge district, eastern Transvaal, South Africa. Unpublished report, Wits Rural Facility, Acornhoek. 178 pp.

SHEIL, D., DUCEY, M.J. and SAMSOEDIN, I., 2003. A new type of sample unit for the efficient assessment of diverse tree communities in complex forest landscapes. *J. Trop. For. Sci.* **15** (1), pp. 117–135.

SHONE, A.K., 1979. Notes on the marula. Dept of Water Affairs & Forestry Bulletin **58,** pp. 1- 89.

SHONGWE, S.P., 1996. Quality of traditional alcoholic beverages of Swaziland. Unpublished BSc dissertation, Faculty of Agriculture, University of Swaziland, Luyengo.

SIDA, 1992. *Trees: Threatened lifeline of northern Namibia.* The people's perspective. Gamsberg MacMillan Publishers, Windhoek.

SIDIBE, D., 2010. Improving the management and productivity of *Tamarindus indica* and *Ziziphus Mauritania* in agroforestry parklands systems in Mali. PhD Thesis, Bangor University, UK.

SILLERO-ZUBIRI, C. and SWITZER, D., 2001. Crop raiding primates: Searching for alternative, humane ways to resolve conflict with farmers in Africa. People and Wildlife Initiative. Wildlife Conservation Research Unit, Oxford University. www.peopleandwildlife.org.uk/crmanuals/CropRaidingPrimatesP&WManual.

SIMONS, A.J., 1996. Delivery of improvement for agroforestry trees. *In* Dieters, M.J., Matheson, C.A., Nikles, G.D., Harwood, C.E. and Walker, S.M.(Eds). Tree Improvement for Sustainable Tropical Forestry. Proceedings of a conference organized by the Queensland Forestry Research Institute. pp. 391-400.

SIMONS, A.J., and LEAKEY, R.R.B., 2004. Tree domestication in tropical agroforestry. *Agroforestry Systems,* **61,** pp. 167–181.

SIMPSON, E., 1949. Measurement of diversity. *Nature* **163**, pp. 68.

SINCLAIR, F., MUETZELFELDT, D., ROBERTSON, M., HAGGITH, D., WALKER, H., KENDON, G. AND RANDELL, D., 1995. Formal representation and use of indigenous ecological knowledge about agroforestry. Final Report of OD Forestry Research Programme Project R4731.

SINGER, M. and WEE, B., 2005. Spatial pattern in checkerspot butterfly-host plant association at local, metapopulation and regional scales. *Ann. Zool. Fennici,* **42**, pp. 347–361.

SINGH, K. and KUSHWAHA, C., 2005a. Paradox of leaf phenology: *Shorea robusta* is a semi-evergreen species in tropical dry deciduous forests in India. *Current Science,* **88,** pp. 1820–1824.

SINGH, K. and KUSHWAHA, C., 2005b. Emerging paradigms of tree phenology in dry tropics. *Current Science*, **89,** pp. 964–975.

SINGH, K. and KUSHWAHA, C., 2006. Diversity of flowering and fruiting phenology of trees in a tropical deciduous forest in India. *Annals of Botany*, **97**, pp. 265-276.

SJAASTAD, E. and BROMLEY, D., 1997. Indigenous land rights in Sub-Saharan Africa: Appropriation, security, and investment demand. *World Development*, **25**(4), pp. 549–562.

SPARKS, J. C., MASTERS, R. E. and PAYTON, M. E. 2002. Comparative evaluation of accuracy and efficiency of six forest sampling methods. *Proc. Okla. Acad. Sci.*, **82**, pp. 49-56.

STEELE, M. And SHACKLETON, C., 2010. Using local experts and benchmarks for household local ecological knowledge: Scoring in South Africa savannas. *Journal of Environmental Management,* **91** (8), pp. 1641 – 1646.

STEENKAMP, C., 1999. Analysis of the woodcarving industry in the Bushbuckridge area. DANCED – Community Forestry Project in the Bushbuckridge area, Department of Water Affairs and Forestry, Nelspruit. 58 pp.

STEHLIK, I, and BARRETT, S., 2006. Pollination intensity influences sex ratios in dioecious *Rumex nivalis*: A wind-pollinated plant. *Evolutio,* **60**, pp. 1207–1214.

STEHLIK, I., FRIEDMAN, J. and BARRETT, S., 2008 Environmental influence on primary sex ratio in a dioecious plant. Proceedings of National Academy of Sciences, USA 105: 10847–10852 .

STEHLIK, I., KRON, P., BARRETT, S., HUSBAND, B., 2007. Sexing pollen reveals female bias in a dioecious plant. *New Phytol.,* **175**, pp.185–194.

STILESE. G., 1977. Coadapted competitors: the flowering seasons of hummingbird-pollinated plants in a tropical forest. *Science*, **198**, pp. 1170-1178.

STORRS, A.E.G., 1979. Know your trees: some of the common trees found in Zambia. Forest Department, Ndola. 380 pp.

STROMGAARD, P., 1989. Adaptive strategies in the breakdown of shifting cultivation: the case of Mambwe, Lamba and Lala of northern Zambia. *Human Ecology* **17**(4), pp. 427-444.

SUTHERLAND, S., 1986. Patterns of fruit-set: what controls fruit-flower ratios in plants? *Evolution,* **40**, pp. 117-128.

SWAI, R. 2001. Effort toward domestication and commercialisation of indigenous fruits of the Miombo woodland in Tanzania: Research and development highlights. *In* Kwesiga, F., Ayuk, E. and Agumya, A. (Eds). Proceedings of the 14th Southern Africa Regional Review and Planning workshop, 3-7th September 2001 Harare Zimbabwe. SADC/ICRAF Agroforestry regional programme.

SWAI, R., MBWAMBO, L., MADUKA, S., MUMBA, M. and OTSYINA, R., 2002. Domestication of indigenous fruit and medicinal trees in Tanzania. Paper presented to the regional agroforestry conference, Agroforestry impacts on livelihoods in Southern Africa: Putting research into practice, Warmbaths, South Africa. 20 – 24th May 2002.

SWEET, G., 1973. The effect of maturation on the growth and form of vegetative propagules of radiata pine. *N.Z. J. For. Sci.* **3**, pp. 191–210.

TALLAK NILSEN, E. and MULLER, W., 1981. Phenology of the droughtdeciduous shrub *Lotus scoparius*: climatic controls and adaptive significance. *Ecological Monographs,* **51**, pp. 323-341.

TANKSLEY, S., 2004. The genetic, developmental and molecular bases of fruit size and shape variation in tomato. *Plant Cell Special Issue*, **16**, S181-S189.

TAYLOR, F. and KWEREPE, B., 1995. Towards domestication of some indigenous fruit trees in Botswana. *In*, Maghembe, J.A., Ntupanyama, Y. and Chirwa, P.W. (Eds.). *Improvement of indigenous fruit trees of the miombo woodlands of southern Africa.* International Centre for Research in Agroforestry, Nairobi. pp. 113–134.

TAYLOR, F.W. and MOSS, H. 1983. The potential for the commercial utilisation of veld products in Botswana. I. The resource and its commercialisation. Unpublished report, Veld products Research, Gaborone.

TAYLOR, F.W., MATEKE, S.M. and BUTTERWORTH, K.J. 1996. A holistic approach to the domestication and commercialization of non-timber forest products. *Non-Wood Forest Products,* **9**, pp. 8-22.

TAYLOR, J.E., 1942. Honey and beeswax production at Zaria. Farm and Forest, **3,** pp.11-14.

TCHOUNDJEU, Z., NGO MPECK, M.L., ASAAH, E. and AMOUGOU, A., 2004. The role of vegetative propagation in the domestication of *Pausinystalia johimbe* (K. Schum), a highly threatened medicinal species of West and Central Africa. *For. Ecol. Manage*. **188**, pp. 175–183.

TEICHMAN, I. VON, 1982. Notes on the distribution, morphology, importance and uses of the indigenous Anacardiaceae. 1. The distribution and morphology of *Sclerocarya birrea* (the marula). *Trees in South Africa*, **34** (3), pp. 35-41.

TEICHMAN, I. VON, SMALL, J.G.C. and ROBBERTSE, P.J., 1986. A preliminary study on the germination of *Sclerocarya birrea* subsp. *caffra. South African Journal of Botany,* **52**, pp.145-148.

TEKLEHAIMANOT, Z., 2008. The role of indigenous fruit trees in sustainable dryland agriculture in Eastern Africa. In: Festus K. Akinnifesi, Roger R.B. Leakey, Oluyede C. Ajayi, Gudeta Sileshi, Zac Tchoundjeu, Patrick Matakala and Freddie R. Kwesiga (Eds.): Indigenous Fruit Trees in the Tropics: Domestication, Utilization and Commercialization., pp 204-223. CAB International Publishing.

TEKLEHAIMANOT, Z., 2005. Indigenous fruit trees of Eastern Africa. The Leverhulme Trust Study Abroad Fellowship Report, 32 pp.

TERRAZAS, T. and CHASE, M.W., 1996. A phylogenetic analysis of Anacardiaceae based on morphology, anatomy and rbcL sequence data. *American Journal of Botany*, **83**, pp. 197-198

TESFAYE, G., TEKETAY, D., FETENE, M. and BECK, E., 2010. Regeneration of seven indigenous tree species in a dry Afromontane forest, southern Ethiopia: Flora - Morphology, Distribution. *Functional Ecology of Plants,* **205**(2), pp. 135-143.

THIONG'O, M.K., KINGORI, S. and JAENICKE, H., 2002. The taste of the wild: Variation in the nutritional quality of marula fruits and opportunities for domestication, *Acta Horticulturae,* **575**, pp. 237–244.

THOMPSON, K. and RABINOWITZ, D., 1989. Do big plants have big seeds? *The American Naturalist,* **133** (5), pp. 722–728.

THORNE, P.J., SUBBA, D.B., WALKER, D.H., THAPA, B., WOOD, C.D. and SINCLAIR, F.L., 1999. The basis of indigenous knowledge of tree fodder quality and its implications for improving the use of tree fodder in developing countries. *Animal Feed Science and Technology*, **81**(1-2), pp. 119-131.

TIISEKWA, B., MAMBA, S.S., NXUMALO, I.S., Du PLESSIS, G., GININDZA, G.J., MHLONGO, B.L. and DUBE, M.M., 1996. Manufacturing procedure, must extraction and wine quality aspects of marula wine and juice commercialisation. Paper presented at a workshop on commercial marula wine production in Swaziland. University of Swaziland, Kwaluseni.

TIMBERLAKE, J.R., 1980. Vegetation map of south east Botswana. Ministry of Agriculture, Gaberone. 83 pp.

TMA, 2010. Tanzania Meteorological Agency, Dar es Salaam.

TODD, C.B., 2001. A survey of fruit production in *Sclerocarya birrea* (marula). Project number 354E3.4. Final Report. Venda University, Thoyhoyandou. 9 pp

TODOROV, S.D. and DICKS, L.M.T., 2009. Bacteriocin production by Pediococcus pentosaceus isolated from marula (*Scerocarya birrea*). *International journal of food microbiology,* **132**(2-3), pp. 117-126.

TRAPNELL, C.G., 1953. *The soils, vegetation and agriculture of north-eastern Rhodesia*, 2nd edn. Government Printer, Lusaka. 146 pp.

TROCHAIN, J., 1940. Contribution à l'étude de la végétation du Sénégal. Mémoires de l'Institut Française de l'Afrique Noire, **2**, pp. 1- 433

TULEY, P. and ALFORD, M.T., 1975. The land resources of central Nigeria: Phase 1, Interim report on the land forms, soils and vegetation of the Bauchi area. Vol. 2. The climate and vegetation. Ministry of Overseas Development Land Resources Division. Miscellaneous Report, **152**(2), pp. 1-238

URVOY (Y.), 1937 - Notes sur la végétation du Sahara soudanais central. *Annales Géograph.,* **46** (261), pp. 270-277.

VAN SCHAIK, C., TERBORGH, J. and WRIGHT, S., 1993. The phenology of tropical forests: Adaptive significance and consequences for primary consumers. *Annual Review of Ecology and Systematics,* **24**, pp. 353-377.

VAN WYK, B. and VAN WYK, P., 1997. Field guide to trees of southern Africa. Struik, Cape Town. 536 pp.

VAN WYK, B. E. and GERICKE, N., 2000. People's plants. A guide to the useful plants of southern Africa. Briza Publications, Pretoria. 351 pp.

VAN WYK, P., 1974. *Sclerocarya caffra* Trees of the Kruger National Park, Purnell, Cape Town.

VARGA, S. and KYTÖVIITA, M. M., 2010 Mycorrhizal benefit differs among the sexes in a gynodioecious species. *Ecology ,* **91**(9), pp. 2583-2593.

VILJOEN, A.M., KAMATOU, G.P.P. and BAŞER, K.H.C., 2008. Head-space volatiles of marula (*Sclerocarya birrea* subsp. *caffra*). *South African Journal of Botany,* **74**(2), pp. 325-326.

VITASSE, Y., DELZON, S., DUFRÊNE, E., PONTAILLER, J., LOUVET, J., KREMER, A. and MICHALET, R., 2009. Leaf phenology sensitivity to temperature in European trees: Do within-species populations exhibit similar responses? *Agricultural and Forest Meteorology,* **149**(5), pp. 735-744

VOLLESEN, K., 1980. Annotated check-list of the vascular plants of the Selous Game Reserve, Tanzania. *Opera Botanica,* **59,** pp. 1-117.

VON MAYDELL, H., 1990. *Trees and Shrubs of the Sahel, Their Characteristics and Uses*. GTZ. Verlag Josef Margraf Scientific Books. Weikersheim, Germany.

VON MAYDELL, H.J., 1986. *Trees and shrubs of the Sahel: their characteristics and uses.* Deutsche Gesellschaft für Technische Zusammenarbeit, Eschborn. 525 pp.

VON TEICHMAN, I., 1983. Notes on the distribution, morphology, importance and uses of the indigenous Anacardiaceae. 2. The importance and uses of *Sclerocarya birrea* (the marula). *Trees in South Africa, 35,* pp. 2-7.

VON TEICHMAN, I., SMALL, J. G. and ROBERTSE, P. J., 1986. A preliminary study on germination of *Sclerocarya birrea* subsp. *Caffra. South African Journal of Botany,* **52,** pp. 145-148.

WAITES, A. and ÅGREN, J., 2004. Pollinator visitation, stigmatic pollen loads, and among - population variation in seed set in *Lythrum salicaria*. *Journal of Ecology*, **92**, pp. 512–526.

WALKER, N. 1989. King of Foods: Marula economics in the Matobos. *African Wildlife*, **43**, pp. 281-285.

WARD, M. and JOHNSON, S., 2005. Pollen limitation and demographic structure in small fragmented populations of Brunsvigia radulosa (Amaryllidaceae). *Oikos*, **108**, pp. 253–262.

WATERMAN, P.G., 1994. Trees for drugs and other extractives: future prospects. *In*, Leakey, R.R.B & A. Newton. (Eds.) *Tropical trees: potential for domestication, rebuilding genetic resources*. HMSO, London.

WATT J.M. and BREYER-BRANDWIJK, M.G., 1962. *The Medicinal and Poisonous Plants of Southern and Eastern Africa* (2nd ed.), Livingstone, London.

WEHMEYER, A.S., 1966. The nutrient composition of some edible wild fruits found in the Transvaal. *South African Medical Journal*, **40**, pp. 1102-1104.

WEINERT, I.A.G., WYK, P.J. VAN and HOLTZHAUSEN, L.C., 1990. Marula. *In*, Nagy, S., Shaw, P.E. and Wardowski, W.F. (Eds). Fruits of tropical and subtropical origin: composition, properties and uses, pp. 88-115. Florida Science Source, Lake Alfred. 391 pp.

WERE, J. and MUNJUGA, M., 1998. Preliminary findings of the storage behaviour of *Prunus africana* and *Sclerocarya birrea* seed in Kenya. Poster presented at Danida Forest Seed Centre/International Plant Genetic Resources Institute project meeting 12-14 October 1998, Kuala Lumpur, Malaysia.

WERGER, M.J.A. and COETZEE, B.J. 1978. The Soudano-Zambezian Region. *Monographiae Biologicae,* **31**, pp. 301-462. Junk, The Hague. 1439 pp.

WHEELWRIGHT, N. and LOGAN, B., 2004. Previous-year, reproduction reduces photosynthetic capacity and slows lifetime growth in females of a neotropical tree. Proceedings of the National Academy of Sciences, USA 101: 8051–8055.

WHEELWRIGHT, N., 1993. Fruit size in a tropical tree species: variation, preference by birds, and heritability. *Vegetation,* **107**, pp. 163 – 174.

WHITE, F., 1983. The vegetation of Africa: a descriptive memoir to accompany the UNESCO/AETFAT/UNSO vegetation map of Africa. Paris. UNESCO.

WILLIAMS, R. J., MYERS, B. A., MULLER, W. J., DUFF, G. A. and EAMUS, D., 1997. Leaf phenology of woody species in a North Australian tropical savanna. *Ecology*, **78**(8), pp. 2542-2558.

WILLIAMS, W., LANCE, G., WEBB, L., TRACEY, J. and CONNELL J., 1969. Studies in the numerical analysis of complex rain-forest communities: The elucidation of small-scale forest pattern, *Journal of Ecology* **57**, pp. 635–654.

WILLIAMS-LINERGA, 1997. Phenology of deciduous and broad leaf evergreen tree species in a Mexican tropical lower montane forest. *Global Ecology and Biogeography Letters* **6**, pp. 115-127.

WINKLERPINS, A.G. and SANDOR, J. A., 2003. Local soil knowledge: Insight, application, and challenges. *Geoderma* **111**, pp. 165 – 170.

WINSOR, J., DAVIS, L. and STEPHENSON, A., 1987. The relationship between pollen load and fruit maturation and its effect on offspring vigor in *Cucurbita pepo*. *The American Naturalist*, **129**, pp. 643-656.

WOJTUSIK, T., FELKER, P., RUSSELL, E. and BENGE, M., 1993. Cloning of erect, thornless, non-browsed nitrogen fixing trees of Haiti's principal fuel wood species (*Prosopis juliflora*). *Agroforestry Systems*, **21**, pp. 293-300.

WOLFE, L. and DENTON, W., 2001. Morphological constraints on fruit size in *Linaria canadensis*. *International Journal of Plant Sciences,* **162**, pp. 1313–1316.

WRIGHT, S.J. and CALDERÓN, O., 1995. Phylogenetic patterns among tropical flowering phenologies. *Journal of Ecology,* **83,** pp. 937-948.

WYK, P. VAN, 1972-1974. *Trees of the Kruger National Park* (2 vols). Purnell, Cape Town. 597 pp.

WYNBERG R., CRIBBINS J., LEAKEY R.R.B., LOMBARD C., MANDER M., SHACKLETON S.E. and SULLIVAN C.A, 2002. Knowledge on *Sclerocarya birrea* subsp. *caffra* with emphasis on its importance as a non-timber forest product in South and southern Africa: A summary. 2. Commercial use, tenure and policy, domestication, intellectual property rights and benefit-sharing. *Southern African Forestry Journal*, **196**, pp. 67–77.

WYNBERG, R., LAIRD, S., SHACKLETON, S., MANDER, M., SHACKLETON, C. M., DU PLESSIS, P., DEN ADEL, S., LEAKEY, R. R. B., BOTELLE, A., LOMBARD, C., SULLIVAN, C., CUNNINGHAM, T. and O'REGAN, D., 2003. Marula policy brief: Marula commercialisation for sustainable and equitable livelihoods. *Forests, Trees and Livelihoods,* **13**, pp. 203- 215.

YAMANO, T. and KIJIMA, Y., 2010. The Associations of Soil Fertility and Market Access with Household Income: Evidence from Rural Uganda. *Food Policy*, **35**, pp. 51-59.

ZIDA, D., SAWADOGO, L., TIGABU, M., TIVEAU, D. and ODEN, P.C., 2007. Dynamics of sampling population in savanna woodlands of Burkina Faso subjected to grazing, early fire and selective tree cutting for a decade. *Forest Ecology and Management,* **243**, pp. 102-115.

ZOLHO, R., 2005. Effect of Fire Frequency on the Regeneration of Miombo Woodland in Nhambita, Mozambique. Master's thesis. University of Edinburgh, UK.

ZUNZUNEGUI, M., AIN-LHOUT, F., JÁUREGUI, J., DÍAZ BARRADAS, M.C., BOUTALEB, S., ÁLVAREZ-CANSINO, L. and ESQUIVIAS, M.P., 2010. Fruit production under different environmental and management conditions of argan, *Argania spinosa* (L.). *Journal of Arid Environments,* **74**(10), pp. 1138-1145.

APPENDICES

Appendix I: Wealth ranking by villagers

A: Kiegea Village

Category	Criteria
Rich	Have 20 acres of land; block house with iron roof; with a bed and mattress; three meals per day; support children education up to secondary school level and can take children to schools away from the village; own up to 50 goats, afford healthcare services even away from the village
Average person	Have 5-20 acres of land; mud/withies house and iron roofed; locally made bed-using tree bark ropes; two meals per day; support children up to primary education and within the village; few goats and at least 25 chicken; poor healthcare
Poor	Have 0-5 acres of land; fully thatched house; no bed-use rags; one meal per day; cannot afford education for children; no livestock

B. Malinzanga Village

Category	Criteria
Rich	Harvest at least 100 bags of maize; own up to 100 cows; block house with iron roofs and enough rooms; own motor vehicle; can take children to good schools outside the village
Average person	Harvest less than 100 bags-average of 25 bags; owns bicycle or motorcycle; use draught animals; non-block house with iron roofs; few livestock- 10-30 cows
Poor	Have no or at most one thatched house; no bicycle; can not afford education to children, healthcare, basic clothing and enough meals; no harvests; no livestock; mostly earn a living by selling labor on other villagers farms/homes

Appendix II: Traditional knowledge questionnaire

A. IDENTIFICATION VARIABLES
1. Name of the interviewer_______________
2. Date of interview_______________
3. Name of the respondent (optional) _______________
4. Questionnaire number _______________
5. Village_______________
6. Ward_______________
7. Division_______________
8 Tribe_______________
9. Year settled in village_______________

Section B. HOUSEHOLD CHARACTERISTICS
8. Characteristics of the respondent

Age	
Gender	
Marital status	
R/ship to the household head	
Level of education	
Occupation	

9. Households size (No. of people) _______________
10. Household age composition

Age	**Males**	**Females**
<5 years		
5-18 years		
19-30 years		
31-45 years		
46-60 years		
>60 years		

C. Livelihood Assessment
11. Means of land acquisition
(a) Inheritance (b) Bush Clearance (c) Buy (d) Hiring (e) Others

12. What is the total size of your farm(s) in hectares?

13. What is the use of your land?

14. How do you manage your land? Mention all types of site/soil/crop management interventions

15. Mention the types of crops grown, indicating whether they cash or food crops as well as estimates of annual yield and prices

Crop	Cash/Food	Yield/yr	Price

16. Estimate the amount of food needed for consumption per year; especially the main food types like maize and beans

17. Where do you sell your crops?
(a) Local Market (b) Middle men (c) Distant Market (c) Others

18. Transportation (mainly road) condition (a) Good (b) Poor (c) No roads

19. Form of crop sold: (a) Processed (b) Raw

20. Means of transport to market place (a) foot (b) bicycle (c) motor cycle (d) van (e) animal

20. Who own trees (i) on farm (ii) in the wild

21. Mention all existing and past laws/by-laws and regulations related to the use of natural resources:

Law/by-law/regulation	Past/existing	Nat. resource applicable

22. Who are the major law makers and enforcers?

22. What are the pros and cons of the law making and enforcing system?
(a) Pros

(b)Cons

22. Do you have access to forest extension services? Explain:

23. Do trees contribute to livelihood or household income earnings? For a No or Yes answer briefly explain how and why.
(a) How

(b) Why

24. Mention barriers and potential avenues towards exploitation of tree resources as an alternative means of livelihood?
(a) Barriers

(b) Possible avenues

25. Prioritize economic/income generating activities indicating criteria/reason

Activity(descending order)	Criteria/reasons

D. *Sclerocarya birrea*
25. Do you know *Sclerocarya birrea*? Since when

26. Is Sclerocarya among the trees you own in your farmland? Why?

27. Did you plant the Sclerocarya or they regenerated naturally?

28. If naturally regenerated, why did you retain the trees?

29. What are the criteria used to select/plant/retain Sclerocarya in your farm?

29. Do you apply them? Why? Are they applicable to other trees?

29. Mention all the known uses of Sclerocarya birrea indicating the ones you use and reason for using or not using

Use	Use/don't use	Reason

31. Form of use (a) Processed (b) raw

32. Do you sell *Sclerocarya* products? If yes, mention them and the corresponding unit price:

Product	Yield/year	Unit Price	Total earnings

33. If you don't sell, why?

35. Are you interested in new tree planting and management programs for conservation and livelihood improvement?

Appendix III: Abundance of species associates of Sclerocarya birrea

		Total count	Trees//ha	Total count	Trees//ha
Village	Species		Wild		Farm
Kiegea	Acaccia senegal	336	49.4	71.0	14.5
Kiegea	Acacia brevispica	0	0.0	29.0	5.9
Kiegea	Acacia gerrardii var. gerrardii	42	6.2	111.0	22.7
Kiegea	Acacia mellifera ssp.melifera	857	126.0	0.0	0.0
Kiegea	Albizia amara	382	56.2	322.0	65.7
Kiegea	Combretum apiculatum	127	18.7	0.0	0.0
Kiegea	Combretum collinum ssp. binderanum	297	43.7	0.0	0.0
Kiegea	Combretum fragans	0	0.0	81.0	16.5
Kiegea	Combretum molle	462	67.9	167.0	34.1
Kiegea	Combretum zeylanica	498	73.2	66.0	13.5
Kiegea	Dalbergia melanoxylon	423	62.2	46.0	9.4
Kiegea	Grewia microcarpa	0	0.0	12.0	2.4
Kiegea	Leucaena glauca	0	0.0	98.0	20.0
Kiegea	Maerua angolensis	0	0.0	101.0	20.6
Kiegea	Markhamia obtusifolia	88	12.9	0.0	0.0
Kiegea	Pteleopis myrtifolia	677	99.6	336.0	68.6
Kiegea	Strychnos henningsii	47	6.9	0.0	0.0
Kiegea	Terminalia sericea	42	6.2	18.0	3.7
Kiegea	Vitex strickeri	127	18.7	0.0	0.0
Kiegea	Xerroderis stuhlmannii	92	13.5	91.0	18.6
Kiegea	Zanthoxylum chalybeum	42	6.2	0.0	0.0
Kiegea	Ziziphus mucronata	0	0.0	31.0	6.3
Malinzanga	Acacia nigrescens	658	56.2	0.0	0.0
Malinzanga	Acacia senegal var. leiorhachis	996	85.1	476.0	8.1
Malinzanga	Acacia tortilis ssp. tortilis	876	74.9	336.0	5.7
Malinzanga	Acacia xanthophloea	73	6.2	0.0	0.0
Malinzanga	Azidarachta indica	365	31.2	0.0	0.0
Malinzanga	Combretum zeyheri	658	56.2	672.0	11.4
Malinzanga	Cordyla densiflora	292	25.0	0.0	0.0
Malinzanga	Delonix elata	73	6.2	0.0	0.0
Malinzanga	Euphorbia tirucalli	292	25.0	0.0	0.0
Malinzanga	Lonchocarpus capassa	219	18.7	241.0	4.1
Malinzanga	Markhamia lutea	73	6.2	0.0	0.0
Malinzanga	Steganotaenia araliacea	73	6.2	0.0	0.0
Malinzanga	Strychnos mitis	292	25.0	0.0	0.0
Malinzanga	Vitex payos	73	6.2	0.0	0.0
Malinzanga	Xeroderris stuhlmannii	219	18.7	0.0	0.0
Holili	Acacia nigrescens	442	74.9	62.0	0.9
Holili	Acacia nilotica	116	19.7	95.0	1.4
Holili	Acacia senegal	0	0.0	152.0	2.3
Holili	Acacia tortilis ssp. tortilis	77	13.1	287.0	4.3
Holili	Albizia amara	281	47.6	0.0	0.0
Holili	Azanza garckeana	179	30.3	0.0	0.0

Holili	Balanites aegyptiaca	0	0.0	86.0	1.3
Holili	Boscia salicifolia	262	44.4	63.0	1.0
Holili	Combretum molle	271	45.9	261.0	4.0
Holili	Crossopteryx febrifuga	93	15.8	237.0	3.6
Holili	Dalbergia melanoxylon	743	125.9	475.0	7.2
Holili	Lannea fulva	226	38.3	362.0	5.5
Holili	Lannea humilis	45	7.6	0.0	0.0
Holili	Lannea stuhlmannii	0	0.0	299.0	4.5
Holili	Sterculia africana	117	19.8	0.0	0.0
Holili	Terminalia brownii	205	34.7	207.0	3.1
Holili	Terminalia spinosa	0	0.0	405.0	6.1