  

Forestry and Forest Products in Ethiopia

Technologies and Issues

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opian Institute of Agricultural Research

Forestry and Forest Products In Ethiopia

Technologies and Issues

Technical reviewers

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Preface

The forests of Ethiopia and elsewhere contribute as source of different products and services that may be used to improve the well-being of population of each country. Forestry, besides its direct contribution to the national economy through wood and non-timber forest products supply, also contributes significantly to various sectors of the national economy such as energy, agriculture, food, industry, health, environment, tourism, etc. In general, the socio-economic contributions of forestry at national scale can be seen from various angles such as employment generation, earning of foreign currency through export, savings through import substitutions as well as indirect contribution through support to other sectors of the economy, particularly agriculture.

The continuous destruction of the natural forests of Ethiopia results directly in the loss of unaccounted plant and animal species as well as in a shortage of fuel-wood, timber and other forest products. Indirectly, it leads to more aggravated soil erosion, deterioration of the water quality, further drought and flooding, reduction of agricultural productivity and finally to an ever increasing poverty of the rural population. Finally, it is obvious that the depletion of forest resources contributes significantly to the climatic and physical environment change. To worsen the matter, the reforestation effort is not, by any means matching with the rate of deforestation Ethiopia faced.

For the last decades, forestry research is becoming a key area to alleviate the problems of deforestation and supplement the shortage of supply of forest products from natural and plantation forests, in part due to timber-harvesting restrictions imposed over a few valuable indigenous species Forestry research contributes to achieve several objectives: to provide high value commercial timbers and fuel wood, to rehabilitate degraded lands, for agroforestry purposes, provide non-timber forest products and sustainably manage our natural forests and the monoculture plantations established.

Forestry research is conducted under federal, regional, and higher learning institutions and they play significant role on conducting and providing appropriate, up-to-date, and applicable technologies and information on several forestry related disciplines to be applicable by the different stakeholders. More importantly, generated technologies and knowledge/information should be disseminated on time.

Forestry research is one of the core research processes of EIAR. Plantation and agroforestry, natural forest, Non Timber Forest Products and Forest Products Utilization are the core research areas under the directorate. After the implementation our BPR, among several improved procedures two of them are highly significant. The first is our research ideas are initiated based on stakeholder's interest and the second research outputs are disseminated properly using different forums: workshops, field days, trainings, exhibitions, manuals, mass media, journal articles, etc. Therefore, the "National Workshop on Forestry Research Technologies Dissemination," held between 29 and 31 May 2012 at EIAR, is one example we used to convey research results of EIAR and other regional and higher learning institutions.

The objective of the national workshop was to present completed forestry research over the last few years. Therefore, this proceeding has a total of 34 scientific papers: eight in plantation and agroforestry, 11 in natural gum resin resources, 8 in other non timber forest products and 7 in wood products utilization research areas. The research technologies may be utilized in a number of forestry and forestry related development, utilization, management, conservation etc, enterprises, and education sectors.

We strongly recommend all stakeholders to read the different articles of different technologies and information obtained in recent years and apply a number of forestry, forest related research, development, and utilization activates as appropriate.

Finally, I would like to forward my grateful thanks to the forestry directorate for the successful organization of the workshop and compilation of the proceedings. My great pleasure and special thanks is to all organizations that sponsored the workshop and publication of this proceeding.

Thank you!

Solomon Assefa (PhD)
Director General
Ethiopian Institute of Agricultural research

Acknowledgments

The Forestry Research Directorate would like to thank the Ethiopian Institute of Agricultural Research (EIAR) for supporting the workshop. We thank His Excellency Mr. Sileshi Getahun, State Minister, Ministry of Agriculture for the opening Speech during the workshop and giving direction where to focus to solve forestry problems through research findings.

All paper presenters and contributors are very gratefully acknowledged for their foremost role to make possible both the workshop and publishing the proceedings.

I would like to acknowledge very much the following institutions for their financial support for the workshop: FARM Africa, Natural Gum Processing and Marketing Enterprise (NGPME), Oromia Forest and Wildlife Enterprise (OFWE) and SOS Sahel. I also acknowledge very much the Food and Agriculture Organization (FAO) Ethiopia, for the financial support for publishing proceedings.

The following researchers are duly appreciated for reviewing the manuscripts that appeared in this proceeding: Dr. Yonas Yohannes, Dr. Tesfaye Bekele, Dr. Abeje Eshete, Dr. Anteneh Tesfaye, Dr. Abayneh Derero, and Mr. Getachew Desalegn.

I am indebted to thank Mr. Abraham Yirgu and Mr. Getachew Desalegn for accomplishing the entire secretariat and organizing activities of the workshop. Further thanks to Mr. Abraham Yigru for all the correspondence and handling of manuscripts he did post-the workshop, sending manuscripts to reviewers, via authors, receiving final version from authors and arranging according to Table of Contents of the proceedings. Thanks to Mr. Getachew Desalegn again for proof reading of the final version of the proceedings and forwarding important comments, doing critical inputs and editorial corrections.

The assistance obtained from W/O Etagne Secretary of Forestry Research Directorate/EIAR during organizing and accomplishing the workshop and proceeding activities is acknowledged.

Wubalem Tadesse (PhD)
Director Forestry Research
Ethiopian Institute of Agricultural research

Welcome Speech

Wubalem Tadesse
Director of Forestry Research
Ethiopian Institute of Agricultural Research

On behalf the Forestry Research Directorate, the organizing team and I, welcome you all to this important National Workshop on Forestry Research Technologies Dissemination**.**

The very objective of this workshop is to disseminate our forestry technologies and information to the national forestry extension sectors; forestry development, conservation and forest products utilization stakeholders, etc. In addition, networking and exchange information among research institutions will be strengthened.

The workshop is organized bringing together completed research projects in the recent years from federal and regional research and higher learning institutions. Hence, a total of 72 manuscripts have been received for the workshop.

The completed projects Articles are categorized under 9 different thematic areas: Agroforestry, Plantation forest, Rehabilitation of degraded lands, Watershed Management, Tree Seed Technology, Natural Forest, Natural Gum and Resin, other NTFPs and Forest Products Utilization. Fourty-six articles will be presented on plenary and two parallel sessions.

The last day in the afternoon, we will discuss on the major issues to be raised during the papers presentations, collaboration among stakeholders and the way forward.

We recognize that the number of papers gathered and to be presented is not comprehensive what it may be available in different institutions. But, this is the first step and we have to continue disseminating our results.

It is repeatedly reported that our country is facing several challenges like resource depletion, food insufficiency, etc. But, in most cases the solutions could be home made. Forestry could play significant role in alleviating most of the challenges, if properly managed and strong linkage among stakeholders is created and strengthened:

- Loss of soil fertility and reduction of agricultural productivity is one important problem. But, we have agorforestry technologies and practices: nitrogen fixing and soil improving trees: *Faidherbia albida*, *Sesbania sesban*, *Acacia saligna,* etc.

- Food insecurity is our long lasting problem in the country. However, forest products contribute significantly by providing cash income and direct food source. There are research based information and technologies on forestry contributions to increase livelihood, alternative raw martial supply to forest industries and over-all socio-economic development in the country.

- We import lumber and other wood products from abroad by millions of USD. But, timber producing about 40 indigenous and introduced species such as *Pinus*, *cupressus, Eucalyptus*, etc. have been adapted, their silvicultural, utilization characteristics studied and utilization technologies identified, widely planted, etc. What remains is applying sustainable plantation management and rational utilization programs.

- Natural gum resins are among the most important NTFPs in the country. There are a lot of challenges in this sector, especially with the main frankincense producing species. However, there are also research outputs, for policy makers, investment and agricultural offices for the sustainable management, conservation and appropriate utilization of the resources.

- Massive and participatory afforestation and reforestation programs are being carried out every year in the country. But, there are challenges on: species site-matching, lack of nursery and site preparation practices, planted forests tending operations, etc. There are several technologies on rehabilitation of degraded lands, seed, nursery and plantation management, etc.

- Forestry research is being conducted by several federal and regional actors. However, we don't have a very well organized national forum for dissemination of our results. Therefore, we have to strengthen our linkage.

I am not saying we have all solutions for all forestry related challenges in the country. We need still to strengthen capacity of forestry research in the country to solve root problems of the forestry sector and emerging issues.

There are research-based solutions generated by different Forestry research and higher learning institutions to alleviate the challenges but not yet disseminated and implemented adequately. If we continue strengthening our capacity and do coordinated efforts, definitely the forestry sector could contribute in solving most of the current challenges related to forest, climate, other natural resources and environment issues.

My deepest appreciation is for all of you for coming to this workshop. Special thanks to FARM Africa, NGPME, Omiya Forest and Wildlife Enterprise, SOS Sahel for their generous financial support. Grateful thank to for the workshop organizing team members.

Opening Speech

His Excellency Mr. Sileshi Getahun,
State Minister of Agriculture

It is my great pleasure, to welcome you all to this National Workshop entitled " National Forestry Research Technologies Dissemination" organized by the Ethiopian Institute of Agricultural Research/Forestry Research Directorate.

As you all know, forest resources are clearly an integral part of global sustainable development. They provide food, feed, fuel, shelter, construction wood, lumber, gums, resins, medicine and livelihood to millions of people. Trees sequester carbon and contribute to mitigation and adaptation to climate change. They are vital in watershed management and ensuring healthy hydrological cycle in our surroundings. Likewise, the Ethiopian forest and woody ecosystems remain to play significant environmental and socio-economic multiple roles.

In our country, the continuous loss of forest resources and un-wise utilization has resulted land degradation problems which is stimulated by soil erosion, loss of soil fertility resulting loss of productivity, sedimentation problems in the lakes and rivers, electric power and irrigation dams, loss of biodiversity which resulted in endangering and extinction of high value tree and shrub species, that can significantly contributed for environmental amelioration, ecological stability and products can be used as direct source of timber and other NTFPs.

The new economic policy framework of Ethiopia recognises a reversal of the current environmental degradation, critical to the overall socio-economic development of the country by way of forest restoration, reducing deforestation, land degradation and increasing agricultural productivity by keeping the balance between replacement and exploitation of the natural resources. There are a number of good gestures shown by Federal and Regional Governments, NGOs, communities in different localities on the massive reforestation programs, area enclosures and watershed based soil conservation practices all over the country.

Presently, the government's long standing believe in the fulfillment of the international commitments to combat desertification, climate change, and the clean development mechanism (CDM) of the Millennium Development Goal (MDG) together with its agricultural led industrialization program is working hard line of reducing forest resources destruction to ensure a sustainable socio-economic development highly amicable with the social and environmental requirements.

We can make difference and bring significant changes by realizing the five year Growth and Transformation plan (GTP) of Ethiopia and achieving our targets set thereof that can also ensure sustainable conservation, restoration, protection, development, management, and rational utilization of forest resources.

Consequently, forestry research under taken by the Federal, Regional and Higher learning institutions has to play essential role on conducting and providing appropriate, up-to-date and applicable technologies and information on several forestry related areas to be applicable by different stakeholders. More importantly, generated technologies should be properly disseminated to be applied on time.

I hope this timely organized National workshop will help to share experiences and create understanding among the participants on forestry research and development issues in Ethiopia. The lessons learnt will help to enhance appropriate management and utilization of our forest resources.

Moreover, this forum should serve to strengthen linkages among forestry research, extension, education, and NGOs working in areas of natural resources. Research agendas should target priority areas of the country and extension sectors have to use the latest research outputs on their forest development, utilization and conservation tasks.

Despite the enormous socio-economic and environmental contributions of forest resource, it has been subjected to rapid destruction for various reasons. Hence, Research and Development Institutions have to work hand in hand to overcome resource degradation. Therefore, it is high time to consider the importance of developing and adopting appropriate technologies suitable for proper conservation, development and utilization of this resource. This effort is in line with the current policy and strategy of the Ethiopian government, which is giving due emphasis to the urgency and importance of conservation and rehabilitation of natural resources of the country. This policy also gives due consideration to the importance of focusing on products that have market value and contribute to improve the well being of the local community and economy of the country.

Finally, I express my since appreciation to all of you for travelling long distances to participate and contribute on this national forestry issue and to all workshop collaborator institutions: The Ethiopian Institute of Agricultural Research, Farm Africa, Natural Gum Processing and Marketing Enterprise, Oromia Forest and Wildlife Enterprise and SOS Sahel. My special gratitude is to the Ethiopian Institute of Agricultural Research//Forestry Research Directorate for its strong commitment to prepare such type of technologies dissemination workshop.

With this brief remark, I wish you all very successful participation and deliberations. Now I declare that the Workshop is officially opened.

Keynote Address

Alemu Gezahegne,
President of the Ethiopian Forestry Society

The role of research in understanding and addressing the multiple functions of forests

The vegetation prevalent in this county are characterized into eight natural ecosystems types. These resources are found extending at different landscapes of the country. Forests are among the important component of these ecosystems. It is well known to you that forest, woodland and wooded vegetation account for about 50% of the total land area of the country (WBISPP, 2004). These forest ecosystems harbour the largest diversity of plant, animal and microbial genetic resources. These constituent of the forest ecosystem have diverse economical, social, environmental and ecological services and benefits. The fauna and flora occupying the forest ecosystem have diverse interactions and hence clear understanding of the interaction is essential for adopting effective and efficient resource management and appropriate utilization options.

Scientific information, useful knowledge and skill about the resource can be attained through the implementation well organised and purposefully research and experimentation on different aspects of the resource. Today, we gathered here to share the information obtained from research findings that have been accomplished in recent years. The research outputs to be presented in the coming two days undoubtedly will provide useful technical inputs that help to overcome some of forest development challenges, introduce new production techniques, and highlight some of the most important contribution of the forest resource in improving livelihood. Some of the research outputs could also put forward the challenges that still need through research attention.

Most of the deliberation to be made in the coming two days could present new research findings for the first time and/or research findings that might have been released sometimes a go. Still there are several other research outputs that have been generated at least in the last three decades and yet not communicated to the end users. This scientific information, published or not yet published may not be easily available to all users who would like to make use of it. Notably, the content of these published research outputs might have targeted the scientific community. Synthesising these information in a manner that could be used by other stake holders need to get emphasis and need to work on it. On the other hand, most of this information cannot be easily accessed by many of the stakeholders. It is therefore, important to consider establishing strong national database system.

The bulk of research outputs to be presented in this national workshop could address issues in few fields of studies. I hope you agree with me that there are still some areas which were not touched up on in our research endeavour. This forum therefore should serve to evaluate which areas need to get more attention in the upcoming research planning and fill the prevailing information gaps.

At this point in time it is important to mention that adequate information is not available on the attributes of the forest to the economy, to the society, to the ecology and to the environment. I deliberately mentioned this to give more emphasis to the issue. The research system is expected to avail these databases to confirm and complement the importance of the forest to the national economy to the society and to the environment. These information are important to use as input for preparation of forest development and management plan, for policy making, revising institutional arrangements, indicate the research capacity gaps and using this information in the generating benefits from the international agreements

At this juncture, I believe it is important to share with you that Hirofumi Uzawa (2004) illustrated that forest, rivers, oceans and other aspects of the environment are essential component of what is known as social common capital. He pointed out that the standard approach of economics tend to measure the value of the forest in terms of the profit to be made by cutting down the trees and selling timbers is in appropriate. Because forests are more than timber, it has multiple functions.

Hence, in estimating the value of the forest it is essential to take into account the non-monetary value of the forest. The forest resources found in the fragile and vulnerable areas has immense contribution in stabilizing the ecosystems through increasing the resistance/resilience of these ecosystems to the climatic change, expansion of desertification and other forms of land degradation. Forests enhance hydrological functions of the upper watersheds through increasing infiltration, reducing run-off, flooding and siltation.

The forest sector also contributes significantly to the national economy. However, there is disagreement on the estimated rates of contribution. The disagreements arise due to lack of adequate database on the financial contribution of the forest at national level. Mostly, this is only considering the value of part of the marketable forest products. If the total economic value of the forest resources is taken into account, the contribution of the forestry sector to the national GDP is expected to be higher.

Ethiopia imports several types and large quantities of wood and wood-based products including sawn lumber, pulp, paper and paper board, panel products, round wood and manufactured products. Hence, developing managing and efficient utilizing of the forests can help to save millions of dollars through import substitution. Some of the commercial tree species that adopted in Ethiopia and that have reasonable mean annual increment be used to produce most of these forest products here in Ethiopia. In this research on wood technology, product diversification, demonstration of manufactured products is essential. In line with this it is important focus on introduction mechanisms of small- scale forest product manufacturing schemes. Creating new market links for forest products is also essential. The research undertaking need to solve the knowledge gap, introduce new products, and come up with improved innovative working techniques. This could assist to bring about new market opportunity and attract more out growers to plant more trees.

It is well understood to all of us that annually million of seedlings were planted in different parts of the country. In most cases the survival rate of the planted seedlings did not seem to be satisfactory. This challenge need to get adequate research attention. I believe we need to analyses this closely and come up with recommendation for improving survival rate. Area closure, one of approach widely used in rehabilitating degraded land also need has been widely practiced in different parts of the country with visible vegetation recovery. The rate of the recovery of the enclosures and the intervention measures required to develop and improve the productivity of the enclosure sites need to be researched.

We need also to develop strong information, knowledge, and skill sharing mechanisms between the researchers, the educators, and development practitioners. It is equally important to establish strong information and data sharing mechanisms. It is also important to work towards addressing the government initiatives.

The Government's desire to develop and maximize the benefits from the Forest Sector is expressed through:

- The release of the recent forest proclamation No. 542/2007 and a historic national forest policy.
- The commitment from the government's side is also manifested in several ways, one of which is the widespread tree planting efforts which gathered special momentum since the beginning of the New Millennium.

- In recognition of the Sector's potential contribution for poverty alleviation, forest development has been incorporated in the government's main policy and strategic documents-including the Climate Resilient Green Economy (CRGE).
- Ethiopia represented the African nations for negotiations on climate change at international level, and has expressed its commitment for the development of the Forest Sector for climate change adaptation and mitigation.
- In addition, the public awareness on the critical functions of forest resources for the socio-economic development of the country and for managing environmental degradation has reached a better level than it is before.
- The watershed development practice being under taken in the last few years.
- Oromia and Amhara Regional States have already started to set up relevant institutions to coordinate and lead the forest development and proper utilization efforts in their respective regions.
- The encouraging trends in the establishment of forest based industries provide new area of research and training opportunities and challenges.

All of these positive conditions provide a remarkable and historic opportunity for the development of Forest Sector for increased contribution to the national economy and environmental management.

Finally, organizing such national workshop has a paramount importance in sharing scientific information, working techniques and establishing linkage between individual researchers and institutions. We need also use this form to identify areas where there are information and technological gaps and future research areas.

Plantation and Agroforestry

The Role of Home Garden Agroforestry in Plant Diversity Conservation in Bale

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Introduction

The expansion of modern agriculture is one of the greatest threats to biodiversity. It has led to deforestation and forest degradation, which in turn led to food insecurity and poverty in many parts of the globe including Ethiopia. Despite this, agriculture dominated landscapes have a role to play in preserving biodiversity. Adoption of sustainable farming practices that utilize and conserve biodiversity may ultimately improve environmental quality and limit agricultural expansion into natural forests as well as the negative impacts of agriculture on biodiversity (Khumalo *et al*., 2012). Home garden agroforestry systems are among the land use systems with the potential to harbor native forest biodiversity (Hylander and Nemomissa, 2008a; 2008b). Home gardens are traditional agroforestry systems where a clearly bounded piece of land immediately surrounding the dwelling house is cultivated with a mixture of perennials and annuals (Das and Kumar Das, 2005; Kabir and Webb, 2008). They are common features in many tropical countries and often exhibit variability in composition and structure depending on socio-economic and ecological conditions (Abebe, 2005; Gebauer, 2005; Kabir and Webb, 2008; Pandey et al., 2005).

Home gardens, as intermediate agricultural systems between rain forests and commercial mono -cropping, have wider socio-economic and ecological roles to play in the development of sustainable agriculture (Abebe, 2005; Alexander, 2003). They have numerous benefits from the perspective of production, conservation and aesthetics (Alam et al., 2005). According to Tolera et al. (2008), home garden agroforestry systems in the Ethiopian highlands host higher diversity of woody species than their nearby natural woodlands or forest lands; thus, providing safe havens for conservation of diverse native plant species. The high diversity of species in these systems contributes to genetic conservation of native species, efficient resource use and biological pest control. In addition, the perennial nature of the systems together with the high species diversity provides important ecological services such as nutrient recycling, soil and water conservation, and reduces environmental deterioration. The high proportion of perennial crops and trees coupled with high species diversity in these systems enables year round production of different crops and other products reducing and spreading the risks. Several studies have been made in Ethiopia on different aspects of home garden (Asfaw, 2001a; 2001b; Asfaw and Nigatu, 1995; Asfaw and Woldu, 1997; Woldyes, 2000; Wassihun *et al*., 2003; Abebe, 2005). For example, enset-coffee based home gardens have a high species diversity (i.e. 78 cultivated and 120 tree species) recorded in 144 households in four districts (Abebe, 2005). Similarly, Wasihun et al. (2003) reported 133 plant species from home gardens of Gamu Gofa zone in southern Ethiopia. Hailu and Asfaw (2011) also reported 135 plant species from central Ethiopia. Home gardening is one of the traditional agroforestry systems practiced among the farming communities in Bale living along the Harenna Afromontane forest margin. Despite this, the extent to which home gardens conserve plant diversity is not yet studied in the area. This study is conducted with the objectives of examining plant species composition and diversity, and assessing density of woody plant species of home gardens in selected districts of Bale.

Materials and Methods

Study sites

The study was conducted in Dello Menna, Harenna Buluk, and Berbere districts of Bale zone, southeastern Ethiopia. Dello Menna and Harenna Buluk belong to similar rainfall and temperature regimes. They are named as Menna Angetu site in this study with Berbere as the other site as it is quite different in its environmental conditions. Environmental characteristics of the study areas are described in Table 1.

Table 1. Physiographic and climatic characteristics of the study sites

Environmental characteristics	Menna- Angetu	Berbere
Latitude (N)	$06^{0}10'$ - $06^{0}31'$	$06^{0}46'$ - $06^{0}51'$
Longitude (E)	$039^{0}30'$ - $039^{0}45'$	$040^{0}04'$ - $040^{0}17'$
Altitude (m)	1314 – 1508	1234 – 1538
Mean annual rain fall (mm)	986.2	600-850
Mean annual temperature (^{0}c)	22.3	-

Data collection

A botanical inventory was conducted in home gardens of 63 randomly selected sample households across the two sites (33 from Menna Angetu and 30 from Berbere sites). The entire area of a home garden was used as a sampling unit for each farm household for plant inventory following methods described by Vogle and Vogl-Lukasser (2004). In each sample home garden, all species of trees, shrubs, climbers, and herbs except grasses encountered were recorded in scientific and vernacular names. All individuals of trees and shrubs were counted and recorded in each home garden. The geographic location and altitude of each sample home garden was recorded using Global Positioning System (GPS). The plant inventory was conducted only once in June 2010.

Data analysis

Each species recorded in home gardens was classified by family and growth habit. Species diversity was described using Shannon – Wiever diversity index. Abundance and frequency for tree and shrub species were calculated. For herbs and climbers, only frequency was determined. Species overlap in home gardens across the two sites was assessed using Sorensen's similarity index. The formulae for computing diversity index and similarity coefficient were indicated below.

Shannon Wiener diversity (*H')* and evenness (*E*) indices:

$$H' = -\sum p_i \ln p_i \quad (1)$$

Where, *H'* = Shannon diversity index; *S* = the number of species; *Pi* = the proportion of individuals or the abundance of the *i*th species expressed as a proportion of total cover; *i*= 1, ln = logbasen, n = 10

Evenness was calculated as the ratio of observed diversity to maximum diversity using the equation:

$$E = H'/H\text{max} \quad (2)$$

Where *H*max = ln*S,*

*H*max is the maximum level of diversity possible within a given population (Kent and Coker, 1992).

Sorensen's similarity coefficient:

$$Ss = 2a/\ (2a+b+c) \quad (3)$$

Where, *S*s = Sorensen's similarity coefficient; a = Number of species common to both samples; b = Number of species in sample 1; c = Number of species in sample 2.

Results and Discussion

Plant species diversity

One-hundred and twenty-seven plant species belonging to 57 families 107 genera were recorded in 63 homegardens in both sites (Appendix 1). The species richness is more or less comparable with the home gardens of Gamo Gofa zone (i.e. 133, Wassihun et al., 2003); central Ethiopia (i.e. 135, Hailu and Asfaw, 2011) and lower than home gardens of Sidama (i.e. 120 tree and shrub species, Abebe, 2005) in Southern Ethiopia. Floristic analysis of the home garden systems showed that both sites exhibited comparable number of families and genera with relatively high number of species in Mena-Angetu as compared to Berebere site (Table 2). In both sites, *Fabaceae* was represented by large number of species and genera. In Mena-Angetu site, the next species rich families to *Fabaceae* were *Poaceae*, Rutaceae, Euphorbiaceae and Lamiaceae with 8, 5, 5, and 5 species each, respectively. *Solanaceae* and *Rutaceae* were the next species rich families to *Fabaceae* in Berbere site with 6 and 5 species, respectively. Mena-Angetu site exhibited high species richness for woody species compared to Berebere site. On the contrary, Berebere site had high Shannon's diversity index and evenness of woody species (Table 3). Sorensen's similarity coefficient showed that the two sites were more or less similar in species composition with 69% similarity coefficient (Table 4). The plant species constitute diverse growth forms including trees, shrubs, herbs, and liana. Trees were the dominant growth forms followed by herbs and shrubs. Generally, woody species dominated the plant species composition of the home gardens in the area (Figure 1).

Table 2. Plant families, genera, and species of home garden agroforestry systems in Menna-Angetu and Berbere.

Mena-Angetu (n* = 33)			Berbere (n = 30)		
Families	Genera	Species	Families	Genera	Species
49	89	102	48	81	92

**- Number*

Table 3. Species richness, evenness, and Shannon-Wiener diversity index of woody species in home garden agroforestry systems of Menna – Angetu and Berbere

Diversity measures	Sites	
	Mena-Angetu	Berbere
Species richness	70	63
Shannon's diversity index	1.3	2.2
Evenness	0.31	0.53
H_{max}	4.25	4.14

Table 4. Sorensen's coefficient of similarity between the two sites

Number of species included in comparison	Number of species in common	Sorensen's coefficient of similarity (%)
127	67	69

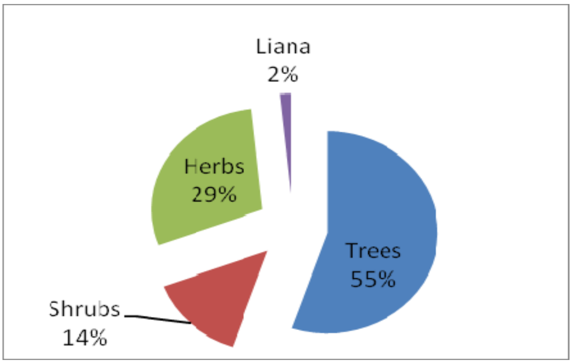

Figure 1. Proportion of the different growth forms observed in the home gardens of Menna – Angetu and Berbere

Density and Frequency

Coffea arabica is the most abundant species followed by *Catha edulis* and *Musa paradisiaca* in Mena–Angetu site. Similarly, *M. paradisiaca, C. arabica* and *Carica papaya* were the three abundant species in Berbere site. *Mangifera indica* is the most frequently observed plant species followed by *M. paradisiaca* and *Persea americana* in Mena–Angetu. *C. papaya* occurred with the highest frequency in Berbere followed by *M. indica* and M. *paradisiacal.* Fruit trees were found to be the most dominant and frequent plant species in both sites. Stimulant plants such as *C. arabica* and *C. edulis* were also among those dominant plant species. This may result from the management practices of farmers that tend to maintain perennial cash crops.

Home garden size and plant species richness

A wide variation in home garden size was observed in the study area ranging from 0.02 to 1.5 ha with a mean of 0.23 ha. Species richness per home garden ranged from 8 to 33 with a mean of 17.7. In Mena–Angetu and Berbere, 17% and 8% of the farmer's land, respectively is allocated for home garden. Home gardens generally constitute 13% of the individual farmland over of the entire study area. The home garden size significantly varied between the sites while the number of species in a home garden remained the same (Table 5).

Table 5. Home garden size and species richness of the study sites

	Sites		P-value
	Mena - Angetu	Berbere	
Home garden size (ha)	0.31 ± 0.3	0.14 ± 0.25	$P \leq 0.019$
No. of species	17.55 ± 5.73	17.8 ± 5.69	$P \leq 0.842$

This may imply that other environmental and socio-economic factors may contribute to species richness than home garden size in this study. The relatively larger home garden size in Mena – Angetu site may result from the fact that home gardens in this site are closer to the Harenna Afromontane forest where farm plots are formed in the form of forest encroachment and people tend to maintain more coffee and other cash crops under the shades of remnant trees. Better accessibility of Mena–Angetu to tertiary roads and local markets could be the other reason.

Home garden components

The study revealed that plant species of multipurpose value designated as other in Table 6 below are the major components of home garden followed by fruits, fodder, and medicinal plants. Table 6 illustrates the proportion of the home garden components based on their respective frequency. The majority of the species grown in home gardens were perennials followed by annuals and biennials in both sites. The life cycle of most of these species is different, making food and other products available throughout the year.

Table 6. Home garden components and their proportion in Menna – Angetu and Berbere

Home garden uses/components	Percent of species in a component (%)
Cereal	2
Fibre	1
Fodder	13
Fruit	18
Medicinal	11
Ornamental	2
Other	33
Pulse	2
Root and tuber	7
Spice	2
Stimulant	4
Vegetable	5

Conclusion

The present study showed that home gardens in selected districts of Bale preserve considerably high plant species diversity. Various home garden components were reported in this study based on the diverse uses of plants by the local community. The species composition is dominated by woody species (trees and shrubs) compared to herbs and lianas. This dominance by perennials increases the complexity of the canopy structure making the system more stable and self-sustaining. The diverse plant species and home garden components recorded in the area would contribute to sustainable agricultural production and provision of other ecosystem services.

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Appendices

Appendix 1. Plant species recorded from home gardens in Bale

Plant species	Growth form	Home garden component	Local name	Family
Acacia abyssinica Hochst. Ex Benth.	T	fodder	Giraar	Fabaceae
Acacia delicocephala Harms.	T	fodder	Qeenxoo	Fabaceae
Acanthospermum hispidum DC.	H	medicinal	Qoree tigree	Asteraceae
Achyranthes aspera L.	H	medicinal	Darguu	Amaranthaceae
Aframomum corrorima (Braun) Jansen	H	Spice	Kororimaa	Zingiberaceae
Afrocarpus gracilior Pilg.	T	other	Birbirsa	Podocarpaceae
Agave sisalana Perr.	T	other	Qaacaa	Agavaceae
Allium cepa L.	H	vegetable	Shinkurtii baaroo	Liliaceae
Aloe citrina Carter and Brandham	S	medicinal	Hargiisa	Aloaceae
Aneilema somaliense C.B. Clarke	H	other	Korma iluu	Commelinaceae
Annona senegalenis subsp. senegalensis Pers.	T	fruit	Giishxaa	Annoniaceae
Yushania alpina K. Schum.	S	other	Leemana	Bambusaceae
Arundo donax L.	S	other	Shambaqoo	Poaceae
Asparagus africanus	C	other	Sariitii	Asparagaceae
Asparagus flagellaris (Kunth) Baker.	C	other	Sariitii	Asparagaceae
Bersama abyssinica Fres.	T	fodder	Araarsaa	Melianthaceae
Brassica carinata A.Br.	H	vegetable	Goomana	Brasicaceae
An identified species	S	other	bubiftuu	Euphorbiaceae

Casava species	T	Roots and tubers	Burkaa	Euphorbiaceae
Cajanes cajan	S	fodder		Fabaceae
Calpurnia aurea	T	Medicinal	Ceekataa	Fabaceae
Canavalia gladiata (Jacq.) DC.	H	pulse	Boloqee	Fabaceae
Capsicum annuum L.	H	Vegetable	Mixmiixaa	lamiaceae
Carica papaya	T	fruit	Baabaa	Caricaceae
Carthamus tinctorius L.	H	pulse	Suuf	Asteraceae
Casimiroa edulis LaLava	T	fruit	Kaashmir	Rutaceae
Casurina equisetifolia L.	T	Ornamental	Shawshawe	Casuarinaceae
Catha edulis Forsk.	T	Stimulant	jimaa	Celastraceae
Celtis africana Burm.f.	T	other	Mataqomaa	Ulmaceae
Cheilanthes viridis	F	other	Balbaxxee	Adiantaceae
Chenopodium album L.	H	Medicinal		Chenopodiaceae
Citrus grandis (L.)	T	fruit	Turungoo	Rutaceae
Citrus limonia Obs.	T	fruit	Loomii	Rutaceae
Citrus sinensis (L.)	T	fruit	Burtukaana	Rutaceae
Coffea arabica L.	S	Stimulant	Buna	Rubiaceae
Colocasia esculenta	H	Roots and tubers	Goodaree	Araceae
Combretum collinum subsp. Binderianum (Kotschy) Okafor	T	Other	Dhandhanssa	Combretaceae
Combretum molle R. Br. Ex G. Gon.	T	other	Rukeessa	Combretaceae
Cordia africana Lam.	T	fruit	Wadeessa	Boraginaceae
Crotalaria emarginella Vatke	H	other	…	Fabaceae

Croton macrostachyus Del.	T	fodder	Bakkaniisa	Euphorbiaceae
Curcuma longa L.	H	Spice	Ird	Zingiberaceae
Cucurbita moschata (Lam.) Pior.	H	other	Buqqee	Cucurbitaceae
Cucurbita Pepo L.	H	vegetable	Dabaaqula	Cucurbitaceae
Cupressus lucitanica Mill.	T	Other	Hindheessa	Cupressaceae
Cussonia holsitii Harms ex Engl.	T	other	Harfatuu	Araliaceae
Cymbopogon citratus (DC.) Stapf.	H	medicinal	Xejisar (Hinxiichoo)	Poaceae
Datura inoxia Mill.	H	medicinal	Manjii	Solanaceae
Datura stramonium L.	H	Medicinal	Asaangira	Solanaceae
Delonix regia (Boj. ex Hook. F.) Rafin.	T	ornamental	Shukeelaa	Caesalpinoideae
Dignathia hirtella Stapf	H	fodder	Marga gurra babal'aa	Poaceae
Diospyros abyssinica (Hiern) F.White	T	fruit	Lookoo	Ebenaceae
Dracena steudneri Engl.	T	other		Dracenaceae
Ehretia cymosa Thonn.	T	fodder	Ulaagaa	Boraginaceae
Ensete ventricosum (Welw.) Sheeseman	T	Root and tuber	Warqee	Musaceae
Erythrina abyssinica Lam. ex. DC.	T	fodder	Waleenaa	Papilionoideae
Eucalyptus camaldulensis Dehn.	T	other	Baargamoo	Myrtaceae
Eucalyptus citrodora	T	Other	Baargamoo	Myrtaceae
Eucalyptus globulus Labill.	T	Other	Baargamoo	Myrtaceae
Euclea racemosa Murr.subsp. schimperi (A. DC.) White	S	medicinal	Mi'essa	Ebenaceae
Ficus elastic	T	fodder	Qilinxoo	Moraceae
Ficus species	T	fruit		Moraceae

Ficus sur	T	fruit	Harbuu	Moraceae
Ficus sycomorus L.	T	fruit	Odaa	Moraceae
Ficus vasta Forsk. Var.	T	fodder	Qilxuu	Moraceae
Filicium decipiens (Wight and Arn.) Thwaithes	T	other	Canaa	Sapindaceae
Flacourtia indica (Burm. f.) Merr.	T	fruit	Akuukuu	Flacourtiaceae
Gossypium arboretum L.	S	fiber	Jibrii	Malvaceae
Grevillea robusta A. Cunn.	T	other	Giraaviilaa	Proteaceae
Grewia bicolor Juss	S	fruit	Harooresa	Tiliaceae
Grewia ferruginea Hochst.ex A. Rich	S	fodder	xaaxessaa	Tiliaceae
Hevia brasilensis	T	other		Moraceae
Hibiscus micranthus L.f.	H	other	Gurbii gurraatii	Malvaceae
Ipomoea batatas Lam.	H	vegetable	Mixaaxisha	Convolvulaceae
Jakaranda mimosifolia	T	Ornamental	Jaakarandaa	Bignoniaceae
Jatropha curcus L.	S	other	Jaatrofaa	Euphorbiaceae
Lannea triphylla (A. Rich.) Engl.	T	other	Handarakuu	Anacardiaceae
Lucaenia pallida	T	fodder	Lukaanaa	Fabaceae
Lycopersicum esculentum Mill.	H	vegetable	Timaatima	Solanaceae
Maesa lanceolata Forssk.	T	fodder	Abayii	Myrsinaceae
Mangifera indica L.	T	fruit	Maangoo	Anacardiaceae
Melia azedarach L.	T	medicinal		Meliaceae
Milletia ferruginea (Hochst.) Bak.	T	fodder	Birbirraa	Papilionaceae
Mimusops kummel A. DC.	T	fruit	Qolaatii	Sapotaceae

Moringa stenopetala (Bak. f.) Cuf.	T	medicinal	Shifarraa	Moringaceae
Murdannia simplex	T	medicinal	Qayyoo	Commelinaceae
Musa paradisiaca L.	T	fruit	Muuzii	Musaceae
Nicotiana tabacum L.	H	Stimulant	Qorondee (tamboo)	Solanaceae
Ocimum basilicum L.Var.thyrsiflorum (L.) Benth.	H	Spice	Bosobilaa	Lamiaceae
Ocimum froskolei Benth	H	spice	Urgoo loonii	lamiaceae
Ocimum lamifolium Hochst.ex Benth.	H	spice	Damaakasee	Lamiaceae
Ocimum urticifolium Roth	H	spice	Urgoo harree	Lamiaceae
Olea eurpeae L.subsp. Cuspidata (Wall.ex G. Don)	T	other	Ejersa	Oleaceae
Pennisitum purpureum Schumach.	S	fodder	Marga arbaa	Poaceae
Persea americana Mill.	T	fruit	Avokaadoo	Lauraceae
Phoenix reclinata Jacq.	S	other	Zambaabaa	Arecaceae
Piliostigma thonningii (Schum.) Milne-Redh.	T	fodder	Liloo	Caesalpinoideae
Prunus persica Stokes.	T	fruit	Poomii	Rosaceae
Psidium guajava L.	T	fruit	Zayituunaa	Myrtaceae
Pterolobium stellatum (Forsk.) Chiove.	S	other	Qontir	Caesalpinoideae
Rhamnus prinoides L. Herit.	S	other	Geeshoo	Rhamnaceae
Rhus natalensis Benth.ex Krauss.	T	fodder	Laboobessa	Anacardiaceae
Ricinus communis L.	T	other	Qoboo	Euphorbiaceae
Rosa richardii	S	Ornamental	Tsige rada	Rosaceae
Ruta chalepensis L.	H	spice	Xeenadam	Rutaceae
Saccharum officinarum L.	S	other	Shonkooraa	Poaceae

Schines molle L.	T	Spice	Qunda Barbaree	Anacardiaceae
Senna obtusifolia (L.)	T	other		Fabaceae
Silene macroselen Steudd.	H	medicinal	Waggartii	Poaceae
Solanum incanum L.	S	other	Hidii	Solanaceae
Sorghum caudatum var. gibbum Stapf.	H	cereal	Mishinga	Poaceae
Sorghum vulgares Pers.	H	cereal	Xinqishii	Poaceae
Spathodia nilotica Seem.	T	Ornamental		Bignoniaceae
Strchynos mytis S. Moore	T	other	Mulqaa	Loganiaceae
Syzygium guineense (Willd.) DC. subsp. Guineense	T	fruit	Gootuu	Myrtaceae
Tagetes minuta L.	H	other	Maxannee	Asteraceae
Tamarindus indica L.	T	fruit	roqaa	Fabaceae
Terminalia brownii Fresen.	T	other	Birdheesa	Combretaceae
Terminalia schimperi	T	other	Dabaqqaa	Combretaceae
Trema guineensis (Schum. and Thomnn.)	T	fodder	Tala'aa	Ulmaceae
Triumfetta pentandra A.Rich.	H	other	Gurbii /karaabaa	Tiliaceae
Urtica simensis Hochst. ex Steud.	H	Medicinal	Doobbii	Urticaceae
Vernonia amygdalina Del.	T	fodder	Eebicha	Asteraceae
Vernonia auriculifera Hiern.	S	other	Reejii	Asteraceae
Warburgia ugandensis Sprague	T	Medicinal	Beeftii	Canellaceae
Zea mays L.	H	cereal	Boqolloo	Poaceae
Zingiber officinale Rosc.	H	Spice	Zingibil	Zingiberaceae

High Priority Native Fodder and Fruit Tree and Shrub Species in Some Woredas of Afar and Somali Regions

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Introduction

Woody species provide products such as fuel wood, timber, food, gum, and resin, medicines that millions of people in developing countries depend on. Woody plant species also provide important environmental and cultural services, including provision of shade to crops and people, soil improvement, erosion control and heritage values. However, many woody plant species are both threatened and declining (Belcher and Schreckenberg, 2007; Rönnbäck et al., 2007; FAO, 2009; Tabuti *et al*., 2010).

Domestication may include indigenous fruit/nut trees, indigenous leafy vegetables, medicinal trees, and melliferous trees (Tchoundjeu *et al*., 2006). Woody plant species domestication is thought to be one of the remedies for reversing the problem of degradation of woody plant species. Tree domestication refers to how humans select, manage and propagate trees where the humans involved may be scientists, civic authorities, commercial companies, forest dwellers or farmers (Simons and Leaky, 2004).The process of tree domestication involves the identification, production, management and adoption of desired germplasm to meet farmer-driven or market-led needs (Roshetco and Verbist, 2000). Tree domestication can be carried out in a participatory manner in which rural communities select, propagate, and manage trees according to their own needs, in partnership with scientists, civic authorities, and commercial companies. It is usually oriented towards specific local markets and encompasses the use of both indigenous knowledge and genetic selection based on scientific principles (Tchoundjeu *et al*., 2006). In the tropics, the trees involved domestication occurs in natural forest, secondary forest, communal fallow lands, plantations, and farms (Simons and Leaky, 2004).

In drylands, the sustainability of traditional animal husbandry is becoming difficult. Therefore, new methods or approaches are needed to address the increasing pressure on natural resources, to secure food availability and create alterative income source. One of the emerging new land uses is agropastoralism, which has been spreading into purely pastoral areas (Halt, 1989). Farming could be considered both a response to food insecurity as well as an economic diversification (Oba, 1998). Regionally, pastoral and agropastoral areas in Ethiopia include Afar, Somali, South Omo of Southern Nations and Nationalities People Regional State (SNNPRS), the Borena and some areas of East and West Hararge Zones of Oromia.

Decreasing lowland grazing areas and fodder availability is becoming a problem in both Ethiopia and elsewhere. Indigenous tree and shrub species have a high potential in sustaining a pastoral system in need of alternatives to shrinking grazing areas (Inam-ur-Rahim et al., 2011). Hence, parkland and other agroforestry techniques that involve fruit, fodder, and other economically important perennial plant species need to be integrated as opportunity and options to back-up sustainable agriculture and as a means to mitigation of climate change in these areas. The availability of wild fruits and fodder species on farmlands and around homestead will help in providing nutritious food and income.

Regional survey of indigenous fruit trees in Ethiopia, Kenya, Uganda, Tanzania, and Sudan resulted in eight priority indigenous woody plant species for domestication with potential to improve dryland agriculture (Teklehaimanot, 2008). The species recommended for domestication were *Adansonia digitata*, *Balanites aegyptiaca*, *Cordeauxia edulis*, *Sclerocarya birrea*, *Tamarindus indica, Vitellaria paradoxa*, *Vitex payos,* and *Ziziphus mauritania*. However, since the study targeted only fruit trees and since it was conducted at a meta-scale, we hypothesized that area specific prioritization of both fruit and fodder species may result in a newer set of priority species. The objectives of the current study w to identify and prioritize fodder and fruit tree species in selected Woredas of Afar and Somali pastoral and agropastoral areas for domestication, and investigate the experiences of the local people in their uses.

Matreials and Methods

Study area

The study was conducted in Amibara, Assaita and Awra woredas/ districts in Afar and in Gursum (Jigjiga Zone) and Boh (Dollo Zone) Woredas in Somali Regional States. The locations were selected in consultation with Afar Bureau of Agriculture and Somali Region Pastoral and Agropastoral Research Institute.

Identification of important fodder and fruit tree species

Identification of high priority native fodder and fruit tree species for domestication was conducted, as this is one of the objectives of the project. Eighteen group discussions were conducted with separate groups of women and men in a total of nine villages (one village each in Hinele, Berga, Hida, Lekora, Halaydebe, Angelele, Fafan and Kubijaro Kebeles) in the four Woredas, and the size of the groups varied from eight to over 20 people. In each village, participants were asked to list important native fruit and fodder species. Then, the use of each species as a fodder or fruit or both was identified and the marketability of products recorded. Then, each group was given the task of rating the species according to their overall contribution to livelihood as very high (5), high (4), medium (3), low (2) and very low (1). Finally, priority species for planting on their own fields were identified and prioritized by the participants.

Data from each of the group discussions was then organized and analyzed. The total score of each of the species and the frequency of selection of each species in the villages were first determined. Then, the relative score, and the relative frequencies were calculated as follows.

$$\text{Relative score (RS)} = \frac{\textit{Sum of scores of the selected species in group scussions}}{\textit{Total scores of all the species selected}} \times 100\%$$

$$\text{Relative frequency (RF)} = \frac{\textit{Number of group discussions in which the species was selected}}{\textit{Total frequencies of all the species selected}} \times 100\%$$

Then, the importance value of a given species was computed as the summation of the relative score and the relative frequency. Separate selections to Afar and Somali Regions were conducted based on their importance values.

Characterization of important fodder tree species

Two separate focus group discussion involving key informants, women, men and professionals were conducted to describe the palatability of the important fodder species to camel, goat, sheep, and cattle.

Selection of native woody species for planting in the fields of pastoralists and agropastoralists

Selection of highly preferred tree species for planting in the fields of pastoralists and agropastoralists was conducted by allowing the participants of group discussions to make well-thought selections on the species they really want to plant. They were made clear that this will mean commitment or expression of interest to plant the seedlings to be prepared in the future. Hence, they were careful in selecting the species for planting. The most preferred species were given 5, and the others were given 4 to 1, in decreasing order of preference. Then, calculations on relative score, relative frequency and importance values were made to select highly preferred trees for planting following the same procedure as given before.

Results

Most important native fodder and fruit trees species

Each group in both Afar and Somali Regions listed woody species, their uses as fodder and fruit, their markatability, and their relative importance to livelihood. Accordingly, the woody species with high contribution to the livelihood of the pastoralists and agropastoralists in either Afar or Somali Regions are given in Table 1 (and in Appendices 1 and 2). *Ziziphus mauritania*, *Cordia sinensis* and *Acacia nilotica* were found to be the three most important fodder and fruit tree species in Afar Region, whereas *Cordia sinensis*, *Ziziphus mauritania*, *Berchemia discolor* and *Grewia villosa* were found to be the four most important fodder and fruit tree species in Somali Region (Table 1).

Preferred woody species for planting

The pastoralists and agropastoralists in Afar and Somali Regions in four out of the five districts showed interest to planting 26 and 15 of those they listed as important for their livelihoods (Appendices 3 and 4). However, the Genbere groups in Boh district did not show any interest to tree planting as they are leading a completely pastoralist life. The high priority species (the first five) selected by the pastoralists and agropastoralists for planting in the remaining four districts (Amibar, Assaita, Awra and Gursum) included *Z. mauritania*, C. *sinensis, A. nilotica*, *T. indica, B. discolor*, *Acacia tortilis* and *Dobera glabra* (Table 2). However, *Z. mauritania* was by far the single most preferred species for planting in both Afar and Somali Regions. Though the contribution of the woody species such as *S. persica*, *Grewia species* and *X. americana* to livelihood were highly valued as shown above in Table 1, they were less preferred for planting by the pastoralists and agropastoralists, and hence could not be included in Table 2, which shows the highly preferred tree species for planting. Area specific important and priority tree species and shrubs are given also in Table 3.

Table 1. Fodder and tree species of high importance to livelihood in Afar and Somali Regions

Species	Vernacular names		Uses	Importance value		Fruits marketed (yes/no)
	Afar	Somali		Afar	Somali	
Acacia nilotica	Keselto		fodder	10.0		no
Acacia tortilis	A'eb	Qudhac	fodder	7.7	6.9	no
Balanites aegyptiaca	Uda		fodder + fruit	6.4		no
Berchemia discolor		Dheen	fodder + fruit		11.8	yes
Cordia sinensis	Medera	Madheedh	fodder + fruit	10.1	13.5	yes
Dobera glabra	Garsa		fodder + fruit	6.9		yes
Grewia ferruginea	Hedayito		fodder + fruit	8.1		no
Grewia pencillata		Hohob	fodder		9.4	no
Grewia villosa		Gomosh	fodder		11.7	no
Salvadora persica	Adayito		fodder + fruit	8.4		no
Tamarindus indica		Hamar	fodder + fruit		6.9	yes
Tamarix aphyla	Segento		fodder	7.4		no
Ximenia americana		Hudeh	fodder + fruit		7.2	yes
Ziziphus mauritania	Kusra	Gob	fodder + fruit	10.5	12.4	yes

Table 2. Highly preferred fodder and tree species for planting

Species	Percent score	
	Afar	Somali
Acacia nilotica (Fabaceae)	18.7	
Acacia tortilis (Fabaceae)	13.7	16.3
Berchemia discolor (Rhamnaceae)		24.5
Cordia sinensis (Boraginaceae)	25.8	23.7
Dobera glabra (Salvadoraceae)	13.5	
Tamarindus indica (Fabaceae)		23.7
Ziziphus mauritania (Rhamnaceae)	30.1	32.7

Most important and preferred species for planting in each Woreda

Among the most important species identified for livelihood, *Z. mauritania* was common to four of the Woredas, and the same species was among those selected for planting in the same (Table 3).

Table 3. Highly important species for livelihood and preferred species for planting in each Woreda

Woreda	Region	Species important for livelihood		Species preferred for planting	
		Scientific name	Vernacular name	Scientific name	Vernacular name
Amibara	Afar	*Acacia tortilis*	Eeb	*Acacia tortilis*	Eeb
		Ziziphus mauritania	Kusra	*Acacia nilotica*	Keselto
		Acacia nilotica	Keselto	*Balanites aegyptiaca*	Uda
		Balanites aegyptiaca	Uda	*Ziziphus mauritania*	Kusra
Assaita	Afar	*Acacia nilotica*	Keselto	*Cordia sinensis*	Medera
		Ziziphus mauritania	Kusra	*Acacia nilotica*	Keselto
		Cordia sinensis	Medera	*Ziziphus mauritania*	Kusra
		Salvadora persica	Adayito		Gerayto
			Kilayto		
Awra	Afar	*Cordia sinensis*	Medera	*Ziziphus mauritania*	Kusra
		Ziziphus mauritania	Kusra	*Cordia sinensis*	Medera
		Grewia ferruginea	Hedayito		Alayto
		Dobera glabra	Garsa	*Commiphora* sp.	Kurbeyta
Boh	Somali	*Cordeauxia edulis*	Yehib	none	none
		Grewia pencillata	Hohob		
		Grewia villosa	Gomosh		
		Grewia sp.	Midhacas		
Gursum	Somali	*Cordia sinensis*	Madheedh	*Ziziphus mauritania*	Gob
		Ziziphus mauritania	Gob	*Berchemia discolor*	Dheen
		Berchemia discolor	Dheen	*Tamarindus indica*	Hamar
		Grewia villosa	Gomosh	*Grewia villosa*	Madheedh

Fodder and livestock species

Camel, goat, sheep, and cattle browse and feed on the leaves and fruits of the woody species, while fruits of *Z. mauritania* are feed resource to none of the livestock; fruits and leaves of *Salvadora persica* are not feed resource to cattle; and fruits of *Grewia sp.* are feed resource only to camel but leaves browsed by both camel and sheep (Table 3).

Marketing of the fruits and fodder resources

It was found from the discussions that the fruits of *Z. mauritania*, *C. sinensis*, *D. glabra*, *T. indica* and *B. discolor*, *Grewia sp*, *X. americana* are marketed for human consumption (Table 1) whereas fruits of *S. persica* and all of the fodder resources are not marketed.

Table 4. Tree and shrub species and their parts use by livestock species, yes (√), no (x)

Tree and shrub species	Livestock species			
	Camel	Goat	Sheep	Cattle
Acacia nilotica leaves	√	√	√	√
Acacia nilotica pods	√	√	√	√
Acacia tortilis leaves	√	√	√	√
Acacia tortilis pods	√	√	√	√
Berchemia discolor leaves	√	√	√	√
Berchemia discolor fruit	√	√	√	√
Cordia sinensis leaves	√	√	√	√
Cordia sinensis fruits	√	√	√	√
Dobera glabra leaves	√	√	√	√
Dobera glabra fruit	√	√	√	√
Grewia species leaves	√	√	√	√
Grewia species fruits	√	x	x	x
Salvadora persica leaves	√	√	√	x
Salvadora persica fruits	√	√	√	x
Tamarindus indica leaves	√	√	√	√
Tamarindus indica fruits	√	√	√	√
Tamarix aphyla leaves	√	√	x	x
Tamarix aphyla fruits	x	x	x	x
Ximenia americana leaves	√	√	√	√
Ximenia americana fruits	x	x	x	x
Ziziphus mauritania leaves	√	√	√	√
Ziziphus mauritania fruits	x	x	x	x

Discussion

Participatory tree domestication can help local populations to improve their food and nutritional security as well as to generate income (Tchoundjeu *et al*., 2006). The prioritization exercise conducted involving women and men group in two regional states and in five Woredas has generated highly valuable information. This survey showed that pastoralists and agropastoralists, both women and men, have a wealth of knowledge on trees and shrubs, their multiple uses and marketability of fodder and fruit products. In all the group discussions, unanimous decisions were made on rating the species according to their overall importance to livelihood beside their uses as fodder and fruit sources and on which of the species to plant. Lack of interest to planting any tree by the Genbere group in Boh Woreda was also undisputed as the pastoralists there were convinced that resources were still abundant. Selected species for planting in Amibara, Assaita, Awra and Gursum were fewer compared to the list on important species because the pastoralists and agropastoralists were convinced that they can still readily get most of them from the natural forests.

Z. mauritania happened to be the most preferred species for planting by the pastoralists and agropastoralists in both regions, followed by *C. sinensis* and *A. nilotica* in Afar region and by *B. discolor*, *C. sinensis* and *T. indica* in Somali region. This set of species have been partly captured as priority fruit tree species for dryland areas (e.g. Teklehaimanot, 2008), but some highly valued fodder and fruit tree species such as *C. sinensis* and *B. discolor*, are new additions to the list. The high priority species selected by the pastoralists and agropastoralists for planting are known for their multiple benefits.

For example, leaves of *Z. mauritania* are used as nutritious fodder for sheeps and goats in parts of India and North Africa. Fruits can be eaten fresh or dried and can be made into a floury meal, butter or a cheese like paste, used as a condiment. The fruits can also be boiled with rice and millet and stewed or baked into jellies and jams (Orwa *et al*., 2009). Botanical descriptions, ecology and distribution, propagation and management, products and services as well as pests and diseases on all the selected species can be found in Orwa *et al*. (2009).

Conclusions and Recommendations

Pastoralists and agropastoralists possess a wealth of knowledge on tree and shrub species, the different parts and their uses. The domestication of native fodder and fruit trees should focus on the identified high priority species such as *Ziziphus mauritania*, *Cordia sinensis, Acacia nilotica*, *Tamarindus indica, Berchemia discolor*, *Acacia tortilis* and *Dobera glabra. However, it should also* be accompanied with other economically important species such as *Moringa stenopetala, Phoenix dactylifera*, *Azadirachta indica, Mangifera indica*, *Opuntia ficus-indica* and *Leucaena species*, which were expressed as additional interesting fodder and fruit tree species by one or more communities during the focus group discussions.

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Germination Performances of Provenances of *Hagenia abyssinica*

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Introduction

Seed germination is one of the most critical phases during plant ontogeny (Norden *et al*., 2008), and its variation can be due to differences in seed source, family, parental nutrition, pretreatments, seed maturity, environmental preconditioning during seed development and seed size (Humara, 2000). Seed size is influenced by morphological characteristics such as diameter and height-to-diameter ratio and the genotype of the mother tree that can lead to observable differences among families at the seedling stage (Carles *et al*., 2009). Norden *et al*. (2008) have reported evidence of a positive association between seed mass and mean time to germinate.

Different germination performances of different provenances have been reported (El-Keblawy and Al-Ansari, 2000; Negash, 2003; Mamo *et al*., 2006; Loha et al., 2006). However, results of provenance differences in germination must be interpreted carefully as fertility power of the species varies from time to time, and might depend on a number of non-genetic factors including previous and present climatic conditions, abundance and coordinated maturation of ovules and pollen grains, thoroughness of wind pollination, as well as occurrence of mass-fruiting (Negash, 2003). A differential germination response for seeds matured at different times of the year in the same population suggests that the variation cannot be explained solely by genetic adaptation to local environments (El-Keblawy and Al-Ansari, 2000).

Hagenia abyssinica (Bruce) J.F. Gmel is a wind-pollinated and wind-dispersed broadleaved dioecious tree species that belongs to the family Rosaceae (Ayele *et al*., 2009.) The species is found in the highlands of Ethiopia with the altitudinal range between 2450 and 3250 m. The species has extremely valuable biological attributes, such as fertile soil formation, soil and rainwater conservation (Negash, 1995). Furthermore, *H. abyssinica* is an important medicinal plant that societies relied on for generations for combating various ailments (Assefa *et al*., 2010). *H. abyssinica* has been logged heavily and selectively and it is one of the endangered tree species in Ethiopia (Negash, 1995). The organization of genetic structure in various populations of the species in Ethiopia has been investigated (Feyissa *et al.*, 2007; Ayele *et al.*, 2009, 2011). However, a multi-location and comprehensive genetic testing on quantitative traits has not yet been conducted in *H. abyssinica*, and hence a project on provenance/progeny testing initiated. The objectives of the study on germination were to determine the effect of seed coat removal on germination percentage and germination rate and evaluate the performances of seed lots of different provenances.

Materials and methods

Seed collection and processing

Seeds of *H. abyssinica* were collected for establishment of multi-location genetic test plantations from 13 provenances, and are labeled numbers in increasing order from north to south (Figure.1).

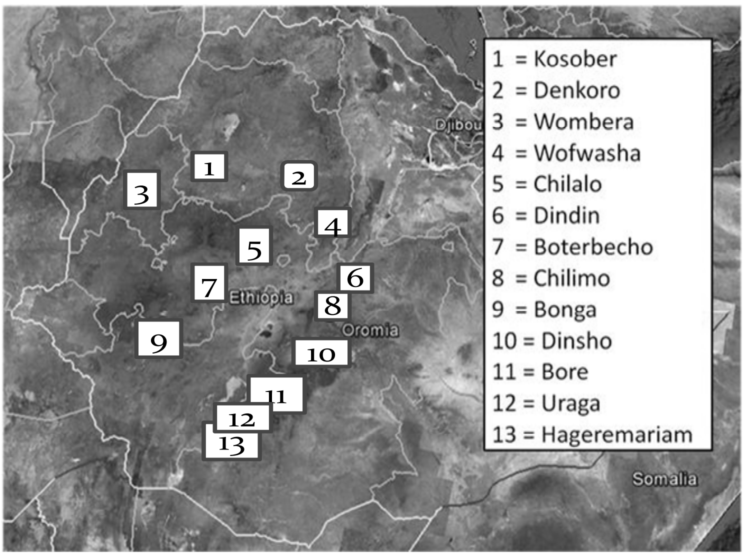

Figure 1. Approximate location of different natural seed sources of *Hagenia abyssinica* in Ethiopia

Seed weight determination

1000 seeds weight of all the 13 provenances was determined by taking 100 seeds in eight replications, following the International Seed Testing Association methodology (ISTA, 1999).

Experiments

Two separate experiments were run taking different populations and under different settings. However, same seedlots were used throughout the experiments. Experiment 1 was conducted using fresh seeds, whereas for experiment 2 stored seeds for 96 to 355 days were used.

Experiment I: During this experiment, moisture content, germination percentage and germination speed of three domestic/local provenances (Bonga, Denkoro and Kosober) were assessed. Then, the seeds were put in oven for 2 hours in 130^{0}C, and allowed to cool in desiccators with the help of silica-jel for 45 minutes. Then, oven dry weight of seeds was measured using analytical balance, and finally the moisture content of the seeds calculated. Germination test was conducted on petri dishes with filter paper. A total of 100 seeds from each provenance were sown in four replications of 25 seeds each. Two sets of seeds were employed: seeds with seed coat removed and seeds without seed coat removal. Counting of germinated seeds was conducted every morning. Germinated seeds were first documented and then removed from the petri dish by forceps, and the test was concluded on the twenty-first day.

Experiment II: Seeds stored at 5^{0}C in cold room in sacks for 96 to 355 days were employed during this experiment, and moisture content and germination performance of all the 13 provenances were assessed. Germination was assessed taking 400 seeds from each provenance, 50 seeds in a petri dish. Data on germination was collected on 100 seeds basis, i.e. counting two petri dishes as one replicate, hence four replicates per provenance.

Data analysis

Germination percentage was computed as cumulative percentage over the germination periods and germination rate as mean of the number of seeds germinated per day. One-way analysis of variance (ANOVA) was performed for determination of testing differences in seed weight among all the provenances. Mean separation was conducted employing least significant difference (LSD) afterwards. Two-way ANOVA was run on seed weight and germination differences among treated/untreated seeds and among the three provenances in experiment 1 (Bonga, Denkoro and Kosober). Investigation of germination differences among stored seeds of all the 13 provenances was carried out employing a univariate ANOVA of germination percentages by provenance with storage time, which was considered as a covariate. All germination percentage data were arcsine transformed for the analysis of variance.

Results

Seed characteristics and effects of seed coat removal on germination

Seed weight

The 1000 seed weight of the 13 provenances based on the data on the weight of the 800 seeds varied from 1.8 to 4.1 g, and the mean weight was 2.5 (± 0.6) g (Table 1). Significant difference in seed weight was revealed among the 13 provenances.

Moisture content and germination in three provenances

Seeds used in experiment 1 had moisture content of 12.7 (±0.3 %). The study on the three provenances (Bonga, Denkoro, and Kosober) of the effect of seed coat removal on germination percentage and its rate revealed significant improvements in both germination percentage and germination rate (Figure 2 and Table 3).

Table 1. Some seed physical characteristics and germination performance of domestic/local provenances in the two experiments.

Provenance	Seed weight	Experiment I			Experiment II		
	1000 seeds weight (g)	% MC	% Germ., over 100 seed coat removed seeds	% Germ., over 100 untreated seeds	Storage time (days)	% MC	% Germ., over 400 seed coat removed seeds
Bonga	4.1[a]	12.5	86	68	278	10.4	66
Denkoro	2.8[d]	12.5	69	36	246	8.7	21
Kosober	2.8[d]	13.1	68	47	312	8.1	45
Bore	2.2[b]				94	10.7	84
Boterbecho	2.3[b]				318	11.1	66
Chilalo	2.0[b]				280	10.5	17
Chilimo	1.8[c]				274	8.5	14
Dindin	2.5[b]				355	11.4	14
Dinsho	2.3[b]				208	7.5	18
Hageremariam	2.2[b]				96	10.4	91
Uraga	1.8[c]				143	7.8	62
Wofwasha	2.2[b]				228	10.8	13
Wombera	3.0[d]				268	10.9	28
Mean	2.5	12.7	74.3	50.3	279	9.8	41
SD	0.6	0.3	10.1	16.3	33	1.4	28

Table 2. Seed weight differences among all the 13 provenances of *H. abyssinica*

Sources of variation	*F*	degrees of freedom	*P*
Provenance	270.93	12	< 0.001
Error		91	

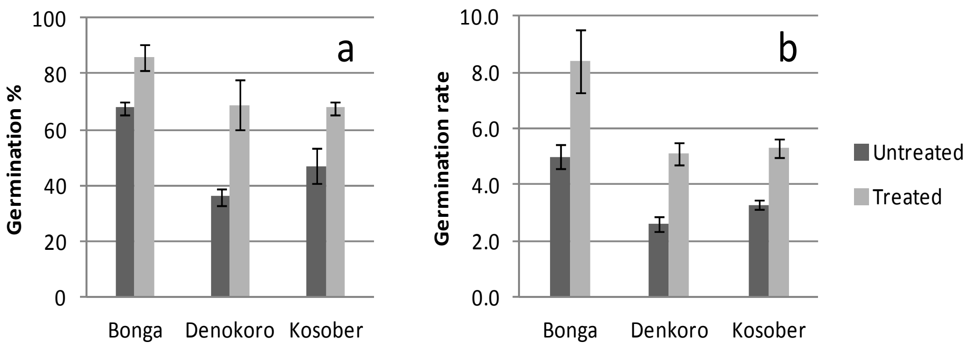

Figure 2. Germination percentage (a) and germination rate (b) of treated and untreated seeds.

Table 3. Germination percentage and rate of germination of treated and untreated seeds of three provenances (Bonga, Denkoro, and Kosober) of *H. abyssinica*

Sources of variation	Dependent variable	*F*	DF	*P*
Provenance	Germination percentage Germination speed	11.95 15.87	2 2	< 0.001 < 0.001
Treatment	Germination percentage Germination speed	30.80 35.93	1 1	< 0.001 < 0.001
Error	Germination percentage Germination speed		20 20	

Moisture content and germination in 13 provenances

Seeds in experiment II had a mean MC of 9.8 (±1.4) % (Table 1). The germination performance of seed coat removed seeds revealed significant differences (p < 0.001) among the 13 provenances (Table 4). The germination performance of Hageremariam and Bore (i.e. 91 and 84%, respectively), was significantly higher than the rest of the provenances (Table 1). Provenances with above-average performance in germination also included Boterbecho, Bonga, and Uraga. The pattern of the germination over time indicated that 66%

of the germination was achieved by day eight, 82% by day 12, 93% by day 16, and 99% by day 20 (Figure 3).

Table 4. Germination percentage differences among the 13 provenances of *H. abyssinica*

Sources of variation	***F***	**DF**	***P***
Provenance	239.54	12	< 0.001
Error		39	

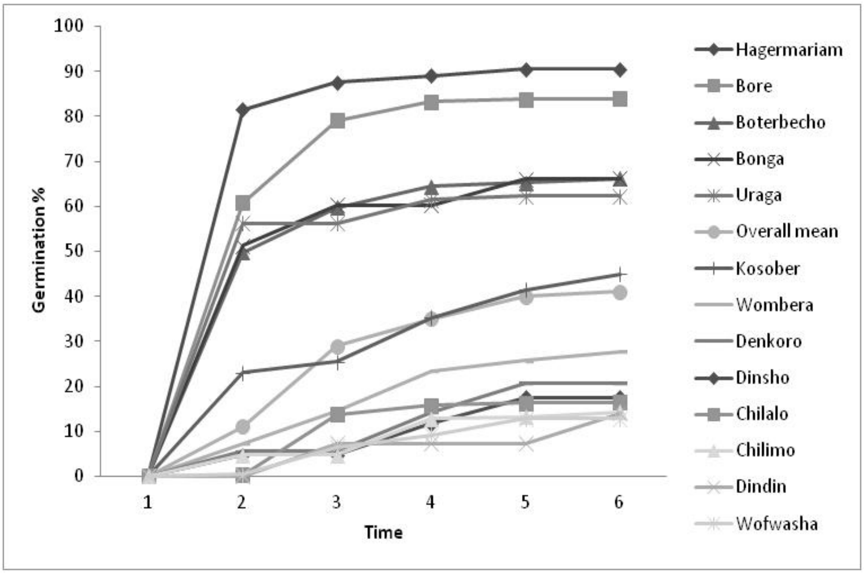

Figure 3. Germination of provenances of *H. abyssinica* over time
1 = day 1, 2 = day 6-8, 3 = day 9-12, 4= day 13-16, 5 = 17-20, 6 = 21-23.

Discussion

Variation in seed lot characteristics and seed size

The genotype and the growing environment of the mother tree influence seed size and weight strongly (Carles et al., 2009). The variability in measured seed weights within and among provenances could indicate the presence of appreciable genetic variation in *H. abyssinica* at both levels. Mean time to germination can be correlated positively with seed mass (Norden et al., 2008), but our data did not allow us to carry out such an analysis.

Effect of seed coat removal on germination

Physiological factors inside the embryo, developmental constraints and mechanical barriers in the fruit or seed coat may prevent germination (Norden et al., 2008). The seed coat removal in *H. abyssinica* could improve both the amount of seeds germinated and the rate of germination. It was evident from the data that ending germination experiments in *H. abyssinica* on the 21st day would mean capturing 99% of the potential germination that could be achieved.

Variation in seed germination among provenances

Edaphoclimatic features of a given area can affect plant growth and seed size and weight, which in turn can affect germination capacity. Hence, marked differences in seed characteristics and germination performances can be observed among different provenances. The significant differences in seed weight and seed germination among the various provenances of *H. abyssinica* revealed in this study signifies the importance of provenance differences, and was in agreement with several other studies (Humara et al., 2000; Negash, 2003).

Storage of seeds for various periods reduced the viability of the seeds differently. For example, the fresh germination level of seed coat removed seeds of six of provenances was not maintained during the study period but decreased varyingly among the provenances (Figure. 4a). In addition, storage time and germination, disregarding provenance differences, exhibited significant negative correlation ($p < 0.001$ and $R^2 = 0.33$) (Figure. 4b). Hence, storage time differences of the provenances in experiment II needed to be overcome by a covariance analysis during the analysis of variance among the provenances.

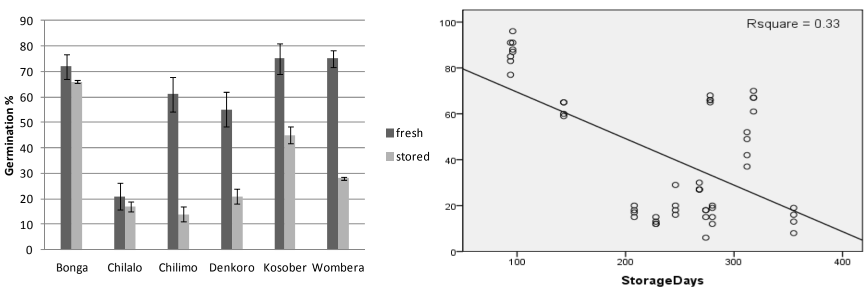

Figure 4. Germination performances of fresh and stored seeds in some provenances (a) and trend of loss of viability with storage time (b) in all the provenances

In addition, germination performances among provenances can partly be explained by variations in age and size (dbh, dbh to height ratio) of the trees, crown development, and the out-crossing rate. However, there can also be considerable variation in germination behavior between different times of seed maturation (El-Keblawy and Al-Ansari, 2000), and fertility power of the species may vary from time to time (Negash, 2003). Hence, interpretation of results from provenance comparisons on seed germination and seed characteristics such as seed weight should be made with caution.

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Provenance Effects on Early Survival and Growth of *Juniperus procera* at Kulumsa, Arsi Zone

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Introduction

Ethiopia has lost and losing much of its vegetation covers at alarming rate (Demel *et al*., 2010). Reusing (1998) indicates a deforestation rate of 163,600 ha/year between 1986 and 1990, and the repot by Gatzweiler *et al*. (2007) and FAO (2009) indicates a deforestation rate of 141,000 ha/year or 0.93% loss per year between 1990 and 2000, which has increased during the period between 2000 and 2005 to 1.04% per year. Ethiopia lost around 2,114,000 ha of forest cover in the last 15 years between 1990 and 2005 (Demel *et al*., 2010). The high rate of deforestation had caused and continues to cause wood famine (particularly shortage of industrial wood), environmental degradation in the form of land and water resources degradation as well as loss of biodiversity, this in turn make an increasing number of Ethiopians vulnerable to climate change effects such as drought and floods or weather extremes in general.

In this regard, plantation establishment is among the prominent means to overcome the acute wood shortage and prevailing environmental degradation while enhancing climate change mitigation and adaptation. With this view, recently, the interest in using indigenous species for afforestation is increasing, however, the knowledge on seed biology and genetic variation of indigenous species is very limited (Aalbeak, 1993). Furthermore, important questions like which species or provenances are better adapted to specific sites need to be answered (Negash and Mebrate, 2005). In Ethiopia, except delineation of tree seed zones based mainly on ecological factors and vegetation types, there is insufficient knowledge about provenance and genetic variability of important indigenous species in general and *J. procera* in particular. Therefore, variability studies for genetic improvement and selection of the best provenance of the desired species for a given site or region is necessary for achieving maximum productivity in plantation forestry (Negash *et al*., 2006).

Juniperus procera is a large coniferous tree common in drier forests of high mountains. The tree reaches a height of 40 meters and has a diameter of more than 100 cm. The bole is straight, often fluted, and sharply tapered. However, there is limited knowledge concerning provenance variations of this indigenous species of Ethiopia regarding their growth performance in different sites and management practices. It was noted that provenances of the same species could react differently to different environmental situations (Negash and Mebrate, 2005). This leads to research question: which provenances are better adapted to specific sites, for this study at Kulumsa? Therefore, this study was initiated with the objective to investigate provenance effects on the early survival and growth performances of *J. procera* at Kulumsa, Arsi Zone.

Materials and Methods

Study site description

The study was conducted at Kulumsa Agricultural Research Center in Arsi zone of Oromia Regional State. Kulumsa is located at 8° 08'N latitude and 39° 08' E longitude, about 167 km Southeast of Addis Ababa and 8 km North of Assela town, the capital of Arsi Zone. The altitude of the area is 2200 m above sea level. The mean annual rainfall is 820 mm, the maximum mean annual temperature is 22.8 °C and minimum mean annual temperature 10.5 °C. The major soil type in the area is Clay soil (Luvisols). The area is characterized by mixed cropping system in which wheat is the major crop.

Study seed zones

A "seed zone" refers to a "region of provenance" or a group of areas with uniform ecological condition where stands showing similar phenotypic or genetic characters for the species concerned are found (Aalbaek, 1993). Based on ecological and geographic variations, 25 major seed zones have been identified and mapped for Ethiopia (Aalbaek, 1993). Out of the 25 seed zones, eight sites representing seven seed zones of Ethiopia were selected and used for this study (Table 1).

Experimental design and lay out

Randomized Complete Block Designs (RCBD) with three replications was used along the contour line to achieve homogeneity within the block. Twenty-five seedlings per plot at a spacing of 2.5 x 2.5 m were planted on July 2005.

Table 1. Details of seed collection areas of *Juniperus procera* provenances

Seed zones/provenance	Specific location	Altitude (ml)	Rainfall (mm)	Temperature (°C)
Western humid undifferentiated Afromontane Forest	Chilimo	2550	1610	15.7
	Kolobo	2500	1610	15.7
Gelemso central undifferentiated Afromontane Forest	Diksis	2764	1265	12.9
Upper Wabe Juniperus forest	Dodola	2675	915	13.9
South eastern highland dry Juniperus Forest	Hirna	2575	1200	13.9
South-eastern lower broad-leaved Afromontane Rainforest	Shakiso	1771	973	18.6
North-eastern drier undifferentiated Afromontane Forest	Wof Wash	2525	1047	14.4
South-eastern dry Juniperus Woodland	Yabelo	2040	744	18.9

Source: Adapted from (Negash and Mebrate, 2005; Negash et al., 2006).

Management

First weeding was carried out six month after planting and then once a year until the seedlings withstand weed competition. Fire outbreak and regeneration of *Acacia* species are common in the planting site, therefore during the study periods slashing and firebreak were carried out whenever needed.

Data collection

Survival count, root collar diameter, and height data were collected at the age of one year after planting and continued each year until the planting materials reached six years old. Diameter at breast height (DBH) measurement was started at the age of five years. For all data, the inner nine trees were sampled to avoid border effects. Root collar diameter and DBH were measured using calipers whereas height was measured using graduated pole.

Data analysis

Data analysis was done using SAS software. The analysis of variance was based on plot means using the model $Y_{ij}=\mu+\alpha_i+\beta_j+\varepsilon_{ij}$, where Y_{ij} is the plot means, μ is the overall mean, α_i and βj are provenances and block effects respectively, and ε_{ij} is random error. The survival data were Arcsine transformed to attain assumption of normality. The relationship between height and root collar diameter and then, DBH growth within the seed zone were determined using correlation analysis.

Results and Discussions

Survival rate

Difference in the survival rate was not significant at P = 0.05 among provenances at all the six years (Table 2). At the age of one year, the survival rate obtained varied from 90.61% to 100 % with the overall mean survival rate of 98.35%. After one years of planting Dodola, Hirna, Shakiso, and Yabelo showed the highest survival rate while Kolobo showed the lowest (90.61%) as compared to other provenances.

Table 2. Mean survival rate (%) of *Juniperus procera* provenances at Kulumsa

Provenance	**Age (year/s after planting)**					
	1	2	3	4	5	6
Chilimo	98.75	98.75	98.75	98.75	98.75	98.75
Diksis	98.75	98.75	98.75	98.75	98.75	98.75
Dodola	100	100	100	100	100	100
Hirna	100	100	100	100	100	100
Kolobo	90.61	90.61	90.61	90.61	90.61	82.84
Shakiso	100	100	98.75	98.75	98.75	98.75
Wof washa	98.75	98.75	98.75	98.75	98.75	98.75
Yabelo	100	98.75	98.75	98.75	98.75	98.75
Mean	98.35	98.20	98.04	98.04	98.04	97.07
ANOVA provenance	ns	ns	ns	ns	ns	ns

Note: ns = not significant at (P = 0.05).

After two years of planting, Dodola, Hirna, and Shakiso were consistently maintained the highest (100%) survival rate, whereas Kolobo still showed the lowest. After three, four and five years of planting, there was no significant change in survival rate within and among provenances and still Dodola and Hirna maintained the highest survival rate (100%) while Kolobo showed the lowest (90.61%) and the overall mean was 98.04%. Similarly, at the age of six years, there was no difference in survival rate. At this age, Dodola and Hirna still maintained 100% survival rate while Kolobo showed the lowest (82.84%), and the overall mean was 97.07% (Table 2).

Survival is the most important variable to be considered in plantation establishment, besides the growth character of provenances. The long-term yield of plantation per unit area can be affected by the mortality or survival of trees (Negash and Mebrate, 2005). In this context, the results showed that the survival rates of all provenances were very good and impressive over the whole six years at Kulumsa site condition. The overall survival rate was varied from 98.35% to 97.07%. The good performance of all *J. procera* provenances at the study site implies that higher survival rate may be achieved if those provenances are used as a seed sources and their seedlings are properly raised, planted, and protected from weed competition.

Height growth

At the age of one year after planting, height growth variation was not significant. Among the tested provenance, Diksis attained the top rank (1.06 m) that followed by Yabelo (0.99 m), Hirna (0.89 m), Chilimo (0.88 m), and Kolobo (0.81 m) respectively. After one years of planting the overall mean height, growth was 0.89 m (Table 3).

Table 3. Mean height (m) of *Juniperus procera* provenances at Kulumsa.

	Age(year/s after planting)					
Provenance	1	2	3	4	5	6
Chilimo	0.88	1.22	1.41	2.32	2.64	2.85
Diksis	1.06	1.31	1.50	2.48	2.84	3.01
Dodola	0.82	1.18	1.49	2.35	2.69	2.83
Hirna	0.89	1.25	1.39	2.52	2.72	2.88
Kolobo	0.81	1.24	1.43	2.45	2.65	2.78
Shakiso	0.83	1.15	1.32	2.27	2.56	2.67
Wof washa	0.86	1.28	1.45	2.71	3.01	3.17
Yabelo	0.99	1.32	1.43	2.45	2.82	2.97
Mean	0.89	1.24	1.43	2.45	2.74	2.89
ANOVA provenance	ns	ns	ns	ns	ns	ns

Note: ns = not significant at (P = 0.05).

In general, like survival rate, mean height growth variation was not significant at all during the six years study periods at (p=0.05). However, Diksis, Wof Washa, Yabelo, and Hirna showed superiority in height growth while the least was showed by provenance from Shakiso. This may be attributed to more or less to altitudinal similarity between Kulumsa (2200 m.) and provenance from Diksis (2764 m a.s.l.), Wof Washa (2525 m a.s.l), Yabelo (2040 m), and Hirna (2575 m) while Kulumsa site is may be too high in elevation or altitude for provenance from Shakiso (1771 m a.s.l.).

Root Collar diameter

Mean root collar diameter at all age is presented in Table 4. Provenances were not showed significant differences in root collar diameter.

Table 4. Mean Root collar diameter (cm) of *Juniperus procera* provenances at Kulumsa.

Provenance	Age(year/s after planting)					
	1	2	3	4	5	6
Chilimo	2.82	3.45	3.70	6.50	7.11	8.03
Diksis	3.00	3.60	4.03	6.86	7.23	7.63
Dodola	2.67	3.27	4.22	7.04	7.57	8.09
Hirna	2.82	3.57	4.08	7.34	7.17	8.35
Kolobo	3.08	3.61	3.67	7.14	7.09	7.86
Shakiso	2.65	3.16	3.62	6.11	6.45	6.98
Wof washa	2.85	3.52	4.33	7.44	7.92	8.74
Yabelo	3.15	3.74	4.20	7.06	7.62	8.32
Mean	2.88	3.49	3.98	6.94	7.27	8.00
ANOVA provenance	ns	ns	ns	ns	ns	ns

Note: ns = not significant at (P = 0.05).

However, relatively provenance from Yabelo attained the highest root collar diameter growth followed by Kolobo and Diksis at the age of one and two years. Provenance from Wof Washa showed the highest root collar growth consistently at age three, four, five, and six years. On the other way, provenance from Shakiso showed the least root collar diameter growth at all ages.

In general, similar to height growth, provenances from Diksis, Wof Washa, Yabelo, and Hirna showed vigorous in root collar diameter growth while the least was showed by provenance from Shakiso consistently at each observation period. This may be attributed to more or less altitudinal similarity or dissimilarity between Kulumsa site and the seed zones.

Diameter at breast height (DBH)

Similar to other growth parameter, diameter at breast height growth variation was not significant among all provenances (Table 5). However, provenance from Hirna attained the top rank (3.26 cm) DBH and followed by Wof Washa (3.23 cm), Diksis (3.01 cm), and Yabelo (2.90 cm) at age five years. At age six years, provenance from Wof Washa recorded the highest DBH and followed by Yabelo (3.62 cm), Diksis (3.56 cm), and Hirna (3.51 cm). The least DBH was recorded for Shakiso at the age of five and six years. In general, provenances (Diksis, Wof Washa, Yabelo, and Hirna) that showed the highest height and root collar diameter growth also recorded the highest DBH, indicating that these provenances perform well at Kulumsa site condition.

Table 5. Mean DBH (cm) of *Juniperus procera* provenances at Kulumsa

Provenance	Age(year/s after planting)	
	5	6
Chilimo	2.68	3.48
Diksis	3.01	3.56
Dodola	2.58	3.24
Hirna	3.26	3.51
Kolobo	2.89	3.35
Shakiso	2.36	2.60
Wof washa	3.23	3.92
Yabelo	2.90	3.62
Mean	2.86	3.41
ANOVA provenance	ns	ns

Note: ns = not significant at (P = 0.05).

The correlation coefficients presented in Table 6 showed that mean root collar diameter growth is positively correlated with height (R^2= 0.85), and with DBH (R^2= 0.91), and mean height growth positively correlated with DBH growth (R^2= 0.86). This implies that provenance with largest DBH and root collar diameter is the tallest.

Table 6.Correlation coefficient of different traits between provenances

	Mean height	Mean RCD	Mean DBH
Mean height	1.00000	0.84686*	0.85892*
Mean RCD	0.84686*	1.00000	0.90653*
Mean DBH	0.85892*	0.90653*	1.00000

*Note: ns = not significant at (P = 0.05), * = significant at P = 0.05.*

Conclusions and Recommendations

In general, the provenances of *J. procera* did not exhibited significant differences on survival and all growth performance parameters (height, root collar diameter, and DBH growth). This may be implied that any of studied provenances of *J. procera* has no difficulty in establishing itself at Kulumsa site. However, based on the overall performance Diksis, Wof Washa, Yabelo, and Hirna provenances showed a better result indicating that any of these seed zones of *J. Procera* has better suited to establish at Kulumsa site and similar agroecologies.

In order to make a firm conclusion as to the genetic variability among provenances, we strongly recommended continuing the observation.

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Strategic Actions for Overcoming Challenges in the Forestry Sector of Ethiopia

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Introduction

The fundamental role, the forestry sector plays to society and environment is well understood. Society will continue to depend on forests for a number of goods and services, which include wood and non-wood products, carbon sequestration, climate amelioration, soil fertility management, soil and water conservation and recreation and tourism. The forestry sector is making a real contribution to employment and economic growth in many countries. However, the scarcity of information on the informal production and employment undermines the contribution of the sector to the national economies (FAO, 2011).

Despite their enormous importance, forests and tree resources are continuing to be depleted from time to time in developing countries, including in Ethiopia. A number of efforts are being made to reversing the situation and improving the forest and tree cover, usually with the involvement of diverse stakeholders.

Recent national efforts with vital implications to the development of the forestry sector include

- Development and issuance of the forest development;
- Conservation and Utilization Proclamation (FDRE, 2007 -Proclamation No. 542/2007), the preparation of a climate change National Adaptation Program of Action (NAPA) (NMA, 2007);
- Ethiopia's Program of Adaptation to Climate Change (EPACC) (EPA, 2010); and
- Nationally Appropriate Mitigation Action (NAMA) (EPA, 2010) and the Forest Carbon Partnership Facility (FCPF) (FDRE, 2011).

Ethiopia is also a signatory to several multilateral environmental conventions including the Biodiversity Convention, the Convention to Combat Desertification, the Libreville Declaration on Health and Environment, the Stockholm Convention.

Besides policies and programs, a number of projects are being implemented on the ground including the massive tree planting campaigns, especially since the new millennia, massive rehabilitation and watershed protection activities and the implementation of participatory forest managements in several forests. Nevertheless, deforestation remains unabated and the tree plantings are not successful, as they ought to be. What are the pressing challenges in the forestry sector, and what strategic actions need to be taken for ensuring the aspired economic and environmental benefits from the sector? Different level of meetings was conducted with various stakeholders in the sector on ensuring integrated forest development (Derero *et al*., 2011a); trends in tree seed system (Derero *et al*., 2011b); and promoting urban forestry (EIAR, 2012) in Ethiopia. The purpose of this paper is to synthesize the findings from the consultative meetings, and avail the outlined strategic actions so that all the actors in the sector may utilize them in project planning and beyond.

Issues

Minimizing deforestation and forest degradation

Deforestation would lead to shortage of wood and non-wood forest products, ecological degradation, and loss of biodiversity, deterioration of watersheds and watershed services and emission of green house gases coupled with minimized carbon sequestration. Clearly, addressing the problems of deforestation and forest degradation will enhance ecosystem services that have knock-on effect on other sectors such as energy and agriculture. Hence, efforts need to be exerted by all the regional states, by all concerned bodies and individuals to halt deforestation and depletion of the remnant natural forests and woodland vegetation of the country.

Most natural high forests in the country are currently receiving inadequate attention in terms of definitive purposes and the sustainable management for achieving the objectives. There is a need for defining clear objectives for the different forest priority areas depending on the resource potential of the respective forest areas.

Strengthening integrated watershed management

Land degradation is one of the main environmental problems of Ethiopia. The problem is highly concentrated in the highlands of the country. About 27 million ha representing 50% of the highlands are already significantly degraded (FAO, 1984). The threat posed by land degradation and soil erosion on the livelihood of millions of people residing in the country is grave. Land degradation and soil erosion also are resulting in economic damage by shortening the life span of reservoirs, siltation of irrigation channels and damaging hydroelectric power generation infrastructure downstream.

Promoting agroforestry

In agroforestry system, fertilizer trees can be integrated with crop production for land regeneration and soil health; fruit trees for nutrition and income; fodder trees for livestock production; timber and fuelwood trees for shelter and energy; medicinal trees to combat disease; and trees that produce gums, resins or latex products (Garrity, 2004). Introduction and proper management of *Faidherbia albida* and other leguminous woody species such as *Cajanus cajan*, *Sesbania sesban*, *Tephrosia spp*, *Acacia spp*, *Callianda calothyrsus*, *Leucena spp* and *Senna spp* increases crop productivity (ICRAF, 2009; Sileshi *et al*., 2009) on maize fields and other major crop fields. Such an intervention will ensure our agricultural landscapes to be evergreen, multifunctional and contribute to the environmental resilience and agricultural sustainability.

Promoting energy forests

Biomass fuels constitute 95% of the total energy consumption, of which firewood and charcoal combined account for more than 77% and agricultural residues (dung and crop residues) an estimated 15% (EREDPC, 2008). While the supply and need for fuelwood varies from place to place, fuelwood deficit is alarming in many parts of the country. The fuel wood requirement of the Ethiopians is estimated 0.8 m^3 per person per annum. This is impossible with the current deforestation rate of 0.34 % per annum, and a huge task is ahead to put a large area under energy forests. Fast growing tree species like *Eucalyptus* and *Acacia* contributed a lot in averting fuel wood crisis in the country, in addition to the harvest from the natural forests and woodlands. The imbalance between wood harvest for energy and the wood production in natural stands and plantations resulted in unsustainable forestry practices, which in turn lead to further degradation of the forest resources. The government of Ethiopia has developed biofuel development strategy, but much needs to be done to put in place good governance and ensure sustainable biofuel development.

Developing industrial plantations

Plantations can contribute a range of benefits to the society. Plantation developments have often been considered as a “quick fix” solutions to the problems of over exploitation of the natural forests. Plantations can meet the required needs of the society provided the right species are planted in the right places and that proper management practices from planning up to implementation phase are put in place. Ethiopia started large-scale industrial plantations in the early 1960's. There have been good examples of industrial plantation development projects carried out in the country in the past. Large-scale plantation development can play a very important role in satisfying demands of proliferating domestic wood industries as well as for export promotion. In addition to that, if the rates of plantation development increased, plantations can serve to alleviate the pressure on the dwindling natural forests.

Ensuring proper land use planning

As pointed out in the global assessment report of agriculture in the Sub Saharan Africa (McIntyre et al., 2009), it is very essential to have proper land use planning to minimize land degradation. Hence, bold decisions need to be made to set aside sloppy areas under continuous vegetation cover, practice land husbandry and rehabilitation activities. Forestlands should stay as permanent estates, thus, should not be converted to other land uses.

Improving the tree seed system

The afforestation and reforestation programs on Ethiopia that took place in the last three decades were not successful due to various reasons. Few of the very important reasons were the use of seeds/seedlings of poor seed source/origin and the existence of poor species/site matching appraoch. Tree seed data in FRC from 2007-2010 indicated that the center on average has been supplying 7,278 kg of pure seeds annually in the stated period satisfying 78% of the request, but apparently the national demand can be much higher. Enhancement of the seed supply requires us to understanding the formal and the informal sector and to identifying the actors and their roles in the tree seed system and working for a common goal in a synergistic fashion. A strong certification system is vital to ensure the functioning of a viable tree seed system and ensure seed quality.

Promoting urban forests

Urban forestry is the art, science, and technology of managing trees and forest resources in and around urban community ecosystems for the physiological, sociological, economic, and aesthetic benefits trees provide society (Konijnendijk et al., 2006). Urban forestry focuses on urban greenspace comprising of tree stands as well as individual trees including all tree-based vegetation in and near urban areas, parks and gardens, nature areas, street and square trees, plantations, woodlots, botanical gardens and trees in residential areas, office compounds, schools, churches, mosques and cemeteries (Alvey, 2006; Konijnendijk et al., 2006; Bentsen et al., 2010). Urban forests can improve the quality of urban life by providing tangible benefits as well as environmental services (Horst, 2006). Urban areas can also contain relatively high levels of biodiversity (Alvey, 2006). The urbanization rate of Ethiopia is one of the largest (about 4-5%) in the world, and its urban population is expected to increase from 15% in 2000 to almost 30% in 2030. Hence, urban forestry merits special attention for both environmental benefits and fighting poverty in Ethiopia.

Building technical capacity

In order to improve the performance and contribution of the sector to the development of the country, it is important to strengthen the capacity of the implementing body at different levels. One of such areas is improving the technical capacity of the staff in the institutions involved in forest development and management. There is serious technical knowledge gap among experts at various levels on various aspects of forestry development.

Developing forestry information system

There is an inadequate information service in the Country. There is a need to gather and compile relevant information; produce bulletins and bibliography, and disseminate them. Such an intervention will have tremendous impact in facilitating information flow among stakeholders, regional states, and the public at large for sustainable forest development and appropriate utilization.

Strengthening linkages in forestry research and development

The lack of a regular consultative forum on forestry research and development has resulted in failure to bringing perspectives, interest, and priorities of the stakeholders in forestry research process and has hampered the extension and use of available forestry technologies in development activities. Due to the very diversity of stakeholders and customers of forestry research, complex nature of forestry and environmental problems, establishing a separate forestry research and extension advisory council that specifically deals with forestry related issues and problems at a national level help to critically deal with the prevailing environmental problems, address the diverse technological needs of customers.

Actions

The following 54 strategic actions were proposed and responsible institutes identified to achieve 11 strategic objectives, and hence alleviate the challenges in the forestry sector (Table 1).

Table 5. Strategic Objectives, Actions, and Responsible Institutions

Strategic objective	Actions	Institutions
Minimize deforestation and forest degradation for sustainable forest resource utilization	• Identify, properly delineate (map), document the existing forest and wood land resources • Develop mechanism for sustainable forest management and utilization • Evaluate existing forest management activities including the various PFM approaches in priority forest areas • Develop mechanisms for economic valuation of forests • Check for possible policy alignment failures and come up with cross-sectoral policies • Initiate efforts to utilizing international provisions in REDD • Undertake plantation establishments for restoration of degraded forest lands • Design and promote efficient energy technologies to minimize deforestation.	EIAR, Bureaus of Agriculture, NGOs, IBC, EPA, State Forestry Enterprises/agencies, Private sector, RARIs, HLIs, Ministry of Trade and Industry, Ministry of Mines and Energy, Federal and Regional Offices
Enhance the role of agroforestry in food security, livelihood improvement and environmental resilience	• Identify suitable and high value species and profitable agroforestry practices for major agroecologies • Promote suitable species and profitable agroforestry practices in selected areas • Document and check success stories in agroforestry • Enhance research and development in tree domestication and value addition of agroforestry products • Optimize and promote traditional agroforestry practices • Promote farm microclimate improvement through tree based systems • 1.7 Integrate agroforestry system with conservation agriculture	EIAR, MoA, Bureaus of Agriculture, NGOs, Private sector, RARIs, HLIs
Strengthen integrated watershed management for rehabilitation of degraded lands and protection of	• Identify key dams and watershed for intervention • Identify key intervention elements, design and implement integrated watershed management on selected water ways	EIAR, Bureaus of Agriculture, NGOs, Ministry of Water Resources, Ministry of Mines and Energy, Ministry of Agriculture, RARIs, Private

major dams	• Evaluate the national experiences of rehabilitation of degraded lands • Scale up success stories to rehabilitate degraded lands • Develop sustainable management plan for rehabilitated areas	sector, EEPCO, Regional EPLAUA
Promote energy forests and ensure sustainable biofuel development	• Identify high priority species for energy • Establish energy forests in peri-urban and rural areas • Design and implement appropriate governance in biofuel development in a cross-sectoral approach • Scale up biofuel technologies	EIAR, MoA, Bureaus of Agriculture, NGOs, State Forestry Enterprises. Ministry of Mines and Energy, RARIs
Develop industrial plantations for domestic consumption and export promotion	▪ Identify suitable species and sites for plantation development ▪ Devise mechanisms (infrastructure, technical support, marketing, concession and management support) to promote investment in industrial plantations ▪ Adapt, develop and implement environmental friendly technologies and management options to increase productivity ▪ Recognize the importance of industrial plantations in meeting economic, social and environmental needs	EIAR, MoA, Bureaus of Agriculture, Private sector, State Forestry Enterprises/Agencies, RARIs
Ensure proper land use planning and its implementation for forest development	• Evaluate existing land use policies and plans and identify gaps • Identify and allocate permanent forest development areas in the land use plans • Prepare and implement land management regulations	EIAR, MoA, Bureaus of Agriculture, State Forestry Enterprises, Regional states
Improve the national tree seed system	• Identify seed collection areas and establish seed stands and orchards for high priority species • Ensure the collection and supply of the priority species through capacity building in the Regional States • Identify seed source owners, seed collectors, seed distributors and private nurseries, and improve the tree seed system • Establish consultation forum for good collaboration and information exchange among actors • Establishing seed storage and networking system • Establish a certification system for tree seed suppliers and ensuring seed quality	EIAR/FRC, MoA, Bureaus of Agriculture, Private seed suppliers and nurseries, NGOs, State Forestry Enterprises/Agencies, Privates sectors RARIs, HLIs, IBC

Promote urban forests for ecosystem services and combating poverty	• Manage green areas sustainably and get legal entitlement to their protection • Create public awareness, engage community and mainstream urban forestry • Strengthen an existing network of actors in urban forestry and related activities • Maximize the role of urban forestry for livelihood improvement and reducing unemployment • Improve the role of urban forests to pollution control and waste management • Rehabilitate degraded areas, restore indigenous forests, and promote biodiversity • Promote agroforestry and fruit tree production	Addis Ababa City Sanitation, Beautification and Parks Development Agency , Addis Ababa EPA, Addis Ababa Urban Agricultural Office, Addis Ababa Water and Sewerage Authority, Department of Landscape Planning and Design, AAU, EPA, EIAR/ FRC, EWPA, Gulele Botanic Garden, IBC, Addis Ababa Land Administration and Development Authority, Ministry of Agriculture, Oromia Forestry Development and Wildlife Enterprise, and Urban Planning Institute
Build technical capacity of institutions involved in forest development , conservation and management	▪ Enable forestry institutions to act on climate change, biofuel, biodiversity, food security and poverty alleviation in integrated way ▪ Enable institutions involved in forestry overcome technical problems in tree planting and management activities	EIAR, Higher learning institutions, MoA, BoA, NGO, State Forestry Enterprises/Agencies, Private sector, RARIs, IBC
Develop forestry information data base and monitoring and evaluation system	• Inventory all forestry related existing information • Establish a standardized reporting system on various forestry activities • Establish an IT assisted documentation system • Establish a monitoring and evaluation system • Release a valid national forestry development report biannually	EIAR, MoA, Bureaus of Agriculture, GO, NGOs, State Forestry Enterprises/Agencies, RARIs
Strengthen linkages in forestry research and development	• Establish national forestry research and development advisory council ▪ Outline the major roles and functions of the council ▪ Determine the mode of operation, functional linkages, coordination and financial arrangements of the council	EIAR, Higher learning institutions, MoA, BoA, NGO, State Forestry Enterprises/Agencies, RARIs

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Micro-Catchment Water Harvesting Systems for Tree Establishment in Dryland areas of Gara Adulala, Ethiopia

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Introduction

The most limiting factor in agricultural production, especially tree establishment in dryland areas is moisture. Arid and semi-arid areas are characterized by low annual rainfall, the distribution of which varies in space and time. The greatest climatic risk to sustained agricultural production in these areas is the inconsistency of rainfall (Anschutz *et al*., 1997). In these areas low and poorly distributed rainfall normally makes tree plantation activities difficult though other factors such as soils and tree species are favorable.

Economic agricultural production in dry areas can be achieved by collecting the water into small areas through water harvesting techniques. For people living in increasingly arid areas, the only water source that could be used with some degree of certainty is harvesting surface run-off (Ouedraogo, 1996). Rainwater is a major water resource for dryland farming due to shortages of surface and ground water (Huang, 2000). Water harvesting methods are classified in several ways, mostly based on the type of use or storage, but the most commonly used classification is based on the catchment size (Oweis *et al*., 2001).

Besides the biological and socio-economic problems, insufficient and variable rainfall and unpredictable variation in rainfall pattern within and between seasons are factors for the failure or successes of afforestation.

Mostly, pits/planting holes are used for tree plantation both at low and high rain potential areas in Ethiopia. Pits retain little runoff during rain seasons from the surrounding catchments, so that seedlings face shortage of moisture and hence, their roots could not establish well.

Seedlings need great protection and care during their early growing period. They need to be protected from browsing and damaging animals. Browsing and trampling can highly influence the growth of tree seedlings. Mostly in

Ethiopia, once tree seedlings are planted they are open for animal encroachment.

Besides the biological and socio-economic problems, insufficient and variable rainfall and unpredictable variation in rainfall pattern within and between seasons in dryland areas affect survival of tree seedlings. It is well known that the critical stage for most trees is the first two years of seedlings/sapling establishment. Trees are relatively sensitive to moisture stress during the establishment stage compared with the ability to withstand drought once their root systems are fully developed (FAO, 1991). In some years, in dryland areas of Ethiopia there occurs shortage of precipitation during rain seasons. Therefore, moisture shortage greatly affects tree seedlings establishment.

Water harvesting can be defined as the process of concentrating rainfall, as runoff from a larger area to be used in a smaller area (Anschutz et al., 1997) .The purpose of micro-catchment water harvesting is to collect runoff from small catchments around crops and storing in the soil profile to increase the soil moisture level. In addition, cover the water requirement of the crops or trees during the growing season (Panda, 2005).

Water harvesting supports a sustainable agricultural production, particularly tree plantation including fruit production in dryland areas, where rainfall is low and erratic in distribution (Oweis *et al*., 1999). Micro- catchments water harvesting can make tree establishment and production possible in dryland areas despite the absence of other water resources. In Ethiopia, millions of seedlings are planted every year but it is observed that survival of seedlings is very low. The major reason out of others is the method of plantation being employed; only planting pits were used for plantation. Pits retain little moisture during rain seasons, while micro-catchment water harvesting helps to increase the moisture storage in deeper layer, which is less prone for evaporation (Panda, 2005). Therefore, identification and application of improved rainwater harvesting structures for tree establishment can solve the problem of tree plantation and production in dry areas. Thus, this paper aims to find out the effective and best performing micro-catchment water harvesting systems for establishment of trees in dryland areas. Therefore, the objective of this study is to identify efficient and improved micro-catchment water-harvesting systems in soil moisture retention for early survival of tree seedlings in dryland areas.

Materials and Method

Description of the study site

The study is carried out at Gara Adulala near Awash Melkassa, which is situated in Adama woreda of East Shewa Zone about 106 km north east of Addis Ababa. The area is characterized as semi-arid area and it is part of the central rift valley of Ethiopia. Long-term mean monthly rainfall as well as 2004 growing season rainfall data during crop season is given in Table 1 (the data were obtained and summarized from MARC metrological station). Weekly rainfall data during crop season are illustrated in Figure 1. Main season rainfall starts in June, reaches at peak in August, and terminates in early September. Mean annual temperature at Awash Melkassa is 21.2 ^{O}C with a mean minimum temperature of 14 ^{O}C and mean maximum temperature of 28.4 ^{O}C. Soils in this region are of diverse type, generally low in organic matter, poor fertility, infiltration and water holding capacity and hence drought prone contributing to periodic crop moisture deficit (Habtamu, 2004; Reddy and Kidane, 1993). The experiment was carried out on enclosed area and certain parts of the mountain's natural vegetation are regenerating. Scattered *Acacia* species are observed in the farmlands. Generally the landscape is highly degraded as a result of centuries human exploitation. It has also suffered from the impact of drought and the pressure of high livestock population.

Table 6. Comparison of growing season monthly rainfall (mm) with mean monthly rainfall of 24 years (1977- 2000) at Melkassa

Year	June	July	August	September	October
1977-200	67.8	188.5	184.7	87.8	48.6
2004	51.2	222.3	136.7	103.4	64.3

Data collection and Analysis

Plots contained four micro-catchments structures namely semi-circular bunds; eyebrow terraces (semi-circular bunds with stone embankments); contour-bench terraces; and infiltration pit (control treatment) randomly distributed in three blocks. Each plot consisted of 20 similar structures. Each structure was replicated three times.

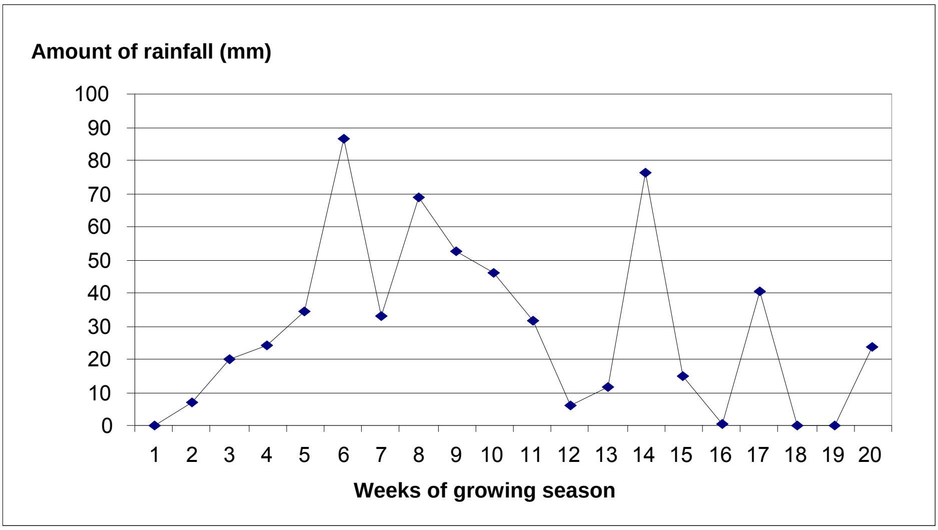

Figure 2. Weekly rainfall pattern of 2004 growing season at Melkassa. Week represents first week of June 2004.

Structures sizes and layout

Semicircular bunds (with soil embankments) were constructed with a radius of 1 m and 30 cm height. Their tips were facing directly upslope, and the embankments were made of soil dug from the area enclosed by the semi-circular. The bunds increase in size from the tip to the bottom (the tips were 10 cm and increasing to 30 cm at the bottom), and at the bottom side an infiltration pit with a size of 40 cm x 40 cm x 40 cm was dug, where the runoff water was collected and plants were planted. The bunds were laid out in staggered rows, with the tips on the contour. Spacing of 50 cm was left between two neighboring structures to let the runoff flow down slope to the next structure.

An eyebrow terrace is a form of semicircular bund, in which its embankments are made of stones and has pit at the center. The designs and layout were the same with semicircular bunds except its embankment was made of stones and the earth inside the area of the bunds were not dug. At the bottom side an infiltration pit, where the runoff water was collected and plants were planted, was dug with a size of 40cm*40cm* 40cm (Figure.2).

Contour-bench terraces were constructed along the contour line with the size of 2 m length, 1 m width, and 30 cm height. Spacing of 50cm was left between the bunds. Same as with the other structures pits with size of 40 cm x 40 cm x 40 cm were dug at the middle of the benches.

Infiltration pits (planting hole) are traditional form of tree planting practice in Ethiopia. The size of each pit in this experiment was 40 cm x 40 cm x 40cm. The pits were 2.5m apart and laid out in staggered rows in the plots. All the infiltration pits are similar with the pits created in each of the above structure. Similarly, each plot consisted of 20 pits.

The design was randomized complete block design. Four types of promising multipurpose trees namely Azadirachta *indica, Schinus molle, Parkinsonia aculeata* and *Acacia saligna* were selected and randomly planted in each of the micro-catchment structures after the runoff has been harvested around the infiltration pits. Spacing between blocks and between plots were 4 m and 3 m respectively, and spacing between the centers of two consecutive structures in the plots (i.e. between plants) was 2.5 m. The structures were aligned in staggered alignments. Spacing of 50 cm was left between two neighboring structures to let the runoff flow down slope to the next structure.

The sizes of the micro-catchment can be decided according to rainfall characteristics/ rainfall amount in space and time, land cover, types of tree species and economical considerations (Anschutz 1997). In this study, the size/area of each structure except infiltration pits was 1.57 m^2. Oweis *et al*.(2001) also suggested that the size of micro-catchment ranges from a few square meters to around 1000 m^2.

Construction of the structures and pits has been taken before rain season in June 2003 and seedlings were planted in July 2003. The growth (height and diameter) and survival of the trees in each structure were recorded in September 2003 and May 2004 and the averages were used for the analysis. The data on survival percentage per structures were analyzed using ANOVA. To determine the statistical differences among treatment means, all treatments were tested at 95% ($P < 0.05$) confidence limits.

Results and Discussion

The result of this study indicates that the micro-catchment water harvesting structures used in this experiment have significant performance differences in contributing to early survival percentage of tree seedlings at 95% confidence limits (Table 2) in dryland areas.

Table 2. ANOVA showing a significant performance difference between structures

Treatments	Survival Percentage (%)
Semi-circular bunds	81.7
Contour-bench terraces	76.7
Eyebrow terraces	40
Infiltration pits	5
LCD	49.72
SE$\pm$	0.28
CV(%)	48.96

Tree seedlings require enough amounts of moisture during their early growing period, especially in the first one or two years that is until they develop new root systems. The extended tap root systems may help them absorb moisture from the depth of the soil. They need to absorb from the reach of their old adventitious root systems. However, once their root systems are fully developed, trees have a high ability to withstand moisture stress.

Hence, tree seedlings require additional moisture to rainwater in dry areas for their early survival. This can be achieved by applying economical and appropriate micro-catchment water-harvesting systems. Water harvesting brings the amount of water available to the plant root zones closer to crop water requirements and thereby permits the growth of seedlings during long dry season (Oweis e *et al*.,t al, 2001; Panda, 2005). Among the micro-catchment, water-harvesting structures used in this study the highest survival percentages were recorded in semicircular bund (81.7%) and followed by contour-bench terraces (76.7%), whereas infiltration pits performed the least (5%). They have different survival rates. Semi-circular bunds have also economic advantages that they are easy to construct and are labor efficient. In addition, a maximum enclosed area is obtained with a minimum of bund volume and they are suitable for uneven terrain because the structures are free standing (Anschutz, 1997). However, a lower survival percentage was recorded (40%) for the eyebrow terraces, which also have different disadvantages. They are used only in areas where stones are available and the establishments and maintenances of this system are labor-intensive (Oweis *et al*., 2001). Infiltration pits are ideal for marginal land where a hardpan surface promotes runoff in to the pits (Ouedraogo and Kabore, 1996). Nevertheless, they are effective only where rainfall distribution is reliable in space and time.

The size of the micro-catchment can be decided according to rainfall characteristics, land cover, crops, and economical considerations (Anschutz, 1997). In this study the size of the structures was small as indicated; this is because the amount of rainfall in this area is relatively better than other parts of semi-arid areas, and this helps to collect enough amount of runoff from a small catchment.

Conclusions and Recommendations

Water harvesting can support insufficient rain during long dry seasons by increasing soil moisture level. Application of an economically appropriate in-situ water harvesting systems in dry areas for tree plantation activities can minimize the loss of planted trees in early growth period and reduce the risk of failure. Thus, knowledge of the effectiveness and the performance of micro-catchment water harvesting systems can help in minimizing the threats of tree plantation in dryland areas.

The most interesting result from this study was that semi-circular bunds and contour-bench terraces were proved effective and the best performing structures in supporting early survival of tree seedlings in dry areas. Therefore, the use of these structures can reduce the risk of loss of seedlings during long drought seasons in moisture stress areas. These structures are not effective in the years with high rainfall due to water lodging in high rainfall areas. However, they are still useful in low rainfall areas.

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Estimation of Variability for some Morphological Traits and Seed Oil Content in Local Physic Nut Population in Eastern Amhara Region

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Introduction

Ethiopia is characterized by varying environments within a small area, which enables various plant species to evolve. There are hundreds of oil-bearing plant species (Seegler, 1983; Getinet and Nigussie, 1997). These include Niger seed, rapeseed, linseed, sunflower, safflower, castor bean, and sesame, which have either their origin or their centre of diversity in Ethiopia. In addition, there are tree species such as palm, physic nut, castor oil desert date and others that bear oil in their fruit and kernel. Of the oil-seed-bearing tree species, physic nut (*Jatropha curcas* L.) is one of the important species that bear seed containing oil with a potential use as biodiesel.

J. curcas L. (Tropical physic nut) belongs to the family *Euphorbiaceae* and genus *Jatropha*. It is native of tropical America probably Mexico and now found throughout the tropics (Ginwal *et al.,* 2004). It lives for up to 50 years, and grows mostly on marginal soils (Henning, 1996). It is a drought-resistant, multipurpose shrub (tree) species, which can reach a height of up to 5 m. It is commonly known as tropical physic nut and locally (in Ethiopia) as ‘Qachima’, ‘Ayderke’, or ‘Kermo Ayderke’. Physic nut is now attracting attention as a source of biodiesel, because of its ability to grow on marginal land (Benge, 2006).

Physic nut is a very prominent and widely commended species with a wide variety of uses. In a country such as Mali, it grows mostly as hedges or live-fences, and protects farms from livestock and reduces water and wind erosion (World Bank, 2002). Locally, women use it as a source of raw material for local soap production, and for medicinal purposes such as wound disinfection, as a purgative, for rheumatism, skin disease, etc. It is also used as a bio-pesticide and molluscicide (Duke, 1983). Above all, its seeds contain about

25–42% of non-edible oil that can be used as a diesel substitute (Jones and Miller, 1992). The oil can also be used for a range of other applications such as lubrication and in the manufacture of soap. The seedcake left after oil extraction is toxic for anilan feed. However, it could be used as fertilizer (Heller, 1996).

Physic nut grows in various parts of Ethiopia, as a hedge around homesteads and farmlands, such as in Wolayita, Metekel, Southern Wollo, northern and Eastern Shewa, Gamo Gofa zones and Gambella region. The local land race of *J. curcas* is adapted for the local environmental and socioeconomic condition indicating the potential of the commercial production. This suggests either that physic nut can be cultivated as large-scale plantations on marginal areas, as small-scale hedges, or intercropped to assist rural livelihoods.

Although physic nut already exists in many places in Ethiopia, its economic importance is far from being realized, owing to technical, economic, cultural, and institutional factors. There is little field experience and documented information about the local population of *J.curcas* of Ethiopia.

Currently, Ethiopia has developed a bio fuel strategy to produce renewable energy source through the cultivation of non-edible vegetable oils, primarily from castor bean and physic nut (Ministry of Mines and Energy, 2007). So far, six foreign and local companies have secured land to be used to grow Jatropha and palm tree in different regions and the ministry has identified 24 million hectares of land suitable to grow Jatropha and palm tree in six regional states (Ministry of Mines and Energy, 2007). This indicates the need to undergo scientific research and development prior to a large scale planting is required for every local area.

The variation in different characters (traits) of *J. curca*s is frequently mentioned in different papers (Heller, 1996; Ginwal *et al.*, 2004; Thongbai *et al.,* 2006; Benge, 2006). For instance, in Jones and Miller (1992) the seed yield reported to vary from 0.4 $ton^{-1}ha^{-1}$ $year^{-1}$ to over 12 $ton^{-1}ha^{-1}year^{-1}$. Again according to Kaushik *et al.* (2007), the oil content of among different accessions collected from different regions of India proved that there is a significant difference in oil content between the accessions, ranging from 28% to 38% of the seed by weight. Again, there is variability in palatability or edibility among the different varieties or population of *J. curcas.* Makkar *et al.* (2002) had reported that there are varieties of *J. curcas* that are edible. In addition, variability in other morphological traits like number of branches per tree, seed weight, seed size and other growth traits of physic nut were reported (Heller, 1996; Ginwal *et al.,* 2004; Kaushik *et al.,* 2007).

The variation in physic nut population may arise from genetic and/or environmental factor. A considerable genetic variation in growth, chemical composition of seed and seed traits at the level of provenance, variety, or progeny can be expected particularly in out-crossing species such as many species of *Albizia, Jatropha, Acacia,* and *Prosopis*, which are widely used in agroforestry systems throughout the worldwide landscapes (Kaushik *et al.,* 2007).

On the otherhand, variation in physic nut population could occur because of its adaptability to over a wide range of rainfall, temperature, and soil types. In central India, variation in physic nut was found mainly due to environment and selection pressure (Ginwal *et al.*, 2004). Populations might have experienced marked differences in selective pressure (Sunil *et al.,* 2007).

Variation in any plant species is useful as a source of future genetic selection provided the desired ideo types for intended purpose of utilization. Development of high-yielding varieties requires a thorough knowledge of the existing genetic variation for yield and its components (Wani and Khan, 2006). So the extent and nature of the variability in genetic, agronomic, physiological traits of physic nut should be quantified for maximum utilization of its genetic potential. This indicates the importance of estimating the variation within the existing local population for yield and yield components investigated prior to investing on large plantation.

Physic nut is an introduced species in Ethiopia, although there is no concerted evidence from where, and when, it was introduced. Since the time and point of introduction of physic nut are not known, it is possible that different gene pools were introduced into Ethiopia at different times. In addition to unclear genetic background of local *J. curcas* population, the diverse agro-ecological regions, and climatic conditions of Ethiopia is expected to offer a good opportunity for variability within the population of *J. curcas* in the country.

So far, nothing has done in Ethiopia, on the understanding and improving the genetic aspects of this species. Systematic evaluation on the yield performance of *J. curcas* from different locations has not yet been carried out in the country and to the necessary extent in the other part of the world. Estimating this variation within the local population of *J. curcas* has paramount importance for initiating a tree improvement program in the country.

Therefore, the main objective of the present study was to estimate the variability in tree morphological traits, seed traits and oil content of local physic nut population in six different sites of Eastern Amhara Region.

Materials and Methods

The Study Area

The study was conducted in eastern Amhara Region, where physic nut is found abundantly. The study area lies between 10°00'–11°26' North latitude and 39°46'–40°25′ East longitude. The area extends from Showa Robit town (Semen Showa Zone) up to Kemise town (Oromiya Zone). Physic nut is specifically found from Shewa Robit to Harbu Kebele, along the main road that stretches from Addis Ababa to Adigrat and then bends towards Bati along the main road to Semera.

In this study area, there are three administrative Zones: South Wollo, North Shewa, and Oromia Zones of Amhara Regional State. The extent of coverage of the study varies, depending on the criteria of the study. Among 18 plots in the study, one site was in Kewet Woreda of Semen Shewa Zone, specifically in Showa Robit Kebele. There were four sites (three plots per site) in four Woredas of Oromiya Zone, namely Jile-Timuga, Artuma Fursi, Dawa Chefa (Kemise) and Bati Woreda. The specific locations were Senbete, Chefa Robit, Kemise, and Bati Kebele, respectively. The last site was in the South Wollo Zone of Kalu Woreda in Harbu Kebele.

The altitude of the Zone ranges between 600 and 3000 m and comprises three agroclimatic zones: *dega, weyna dega* and *kolla,* which account for about 2.6%, 26.2% and 71.2% of the area of the zone, respectively.

Rainfall data at meteorological stations of Bati (1660 m a.s.l.), Kemise (1450 m a.s.l.) and Artuma (1920 m a.s.l.) indicatd that the zone receives major rains in summer, preceded by a small rainfall peak in spring or by a prolonged period of moderate rainfall. The long-term (20 years for Bati and 15 years for both Kemise and Artuma) mean annual rainfall was 851 mm, 1035 mm and 1425 mm, respectively (Degefa, 2001).This means that, despite its higher altitude, Bati has a lower rainfall than Kemise, which is partly explained by the difference relative to the moisture-bearing winds. The temperature in Oromiya Zone decreases sharply from the top of the escarpment in the west to the floor of the Rift Valley in the east. About seven thermal belts exist in the zone, and the mean temperature during the growing seasons ranges 10 °C–27.5 °C (Degefa, 2001).

According to MOA/FAO (1984), six major soil associations cover the landscape of the Oromiya Zone. These are Lithosols, Eutric Cambisols (Lithic), Eutric Cambisols (stony), Eutric Regosols (Lithic), Chromic Vertisols and Orthic Solonchaks. Four sites were selected and established in different parts of the zone. These were Senbete, Chefa Robit, Kemise, and Bati, with 12 plots.

The third zone was South Wollo, which is one of the ten Zones in the Ethiopian Amhara Region. It is bordered on the south by North Shewa and the Oromia Region, on the west by West Gojjam, on the northwest by South Gondar, on the north by North Wollo and on the east by the Oromia Zone. Its highest point is Mount Amba Ferit. Kalu is one of the 105 woredas in the Amhara Region of Ethiopia, and it is part of the South Wollo Zone. Towns in Kalu include Ancharo, Degaga, and Harbu. The altitude of this Woreda ranges from 800 m a.s.l. in the lowlands bordering the Afar Region, to 1,750 m a.s.l. at the foot of the mountains north of Kombolcha. The climate of Kalu varies from dry sub-humid to semi-arid. Important rivers include the Cheleleka and Borkana.

Data Collection

One-hjundred and sixty-two trees, making 18 families, were taken for recording of tree and seed traits and oil content. A random branch count and capsule count from each of the sample trees were made directly in the field, after supplementary data, *e.g.* DSH (diameter at stump height ≅ 0.1 m) and height were gathered. A sample of one kg of seed was collected from all fertile branches of each sample tree, for recording of seed data and oil content (Kaushik *et al.,* 2007).

The geographical location and elevation were determined by direct personal observation, using a Garmin GPS 76. Meteorological data for each site were gathered from Kombolcha meteorology sub-center of Ethiopian Meteorology Agency. The soil-type information was collected from secondary sources, such as reports from various institutions, the Woreda, and interviews with experts.

A graduated measuring stick and caliper were used to measure a sample describing data; these were height and DSH of the sample tree, respectively.

The tree morphological traits data were gathered, first by counting the branch and capsule on the sample trees in the field to compute the value of number of branch per tree, number of capsule per tree and number of seed per tree following a randomized branch sampling method of Jessen (1955).

The seed size traits were the second type of traits determined in the laboratory. First, the sample seeds were separated from the capsules through manual threshing. The seed size traits, namely seed length, seed breadth and seed thickness or width were measured from the seed sample of each unit. Five samples were drawn from each seed sack, and measured for length, width, and thickness (mm) with a caliper. Sampling of seeds from each sample bag from a particular individual was conducted according to the procedure used by Kaushik *et al.* (2007).

For seed weight, five samples of seed, of 100 seeds each, were taken from each seed lot and weighed in gram (± 10mg) on a digital balance in the laboratory, and as for Kaushik *et al. (*2007), all samples of seed were dried under similar temperature and humidity conditions until no change in weight of the seed is observed. As for seed size traits, five randomly drawn samples of seeds from each sample were used to measure the above characters, and averaged to give the specific value of these traits.

The oil content of moisture-free seed was measured by means of magnetic resonance spectroscopy, at Holleta Agricultural Research Center (HARC). Nuclear Magnetic Resonance (NMR) is the preferred method, as it is non-destructive (Getinet *et al.*, 2008), and can reduce the error that potentially is induced by the efficacy of the extraction process.

Flowering in *Jatropha* occurs at the end of the rainy season. After two to four months, the capsules tend to mature and become ready for harvesting (Jones and Miller, 1992). The data were collected in December 2007, which was within the limits of the maturity period, as assessed from information gathered about flowering, before data collection.

Secondary data about the sample site were obtained through personal observation or by direct measurement and secondary sources. These background data include geographical location, elevation, climate, and soil type. In addition, descriptive data on sample trees like tree height and diameter at stump height were gathered.

A count of branch numbers, capsule and seed numbers was made on each of the selected sample trees. The number of branches per tree, number of capsule per tree and number of seeds per tree were determined in the field. These tree traits were considered as tree morphological traits, which determine the overall seed yield per tree, as well as per hectare (Heller, 1996).

Seed size traits (seed length, seed breadth and seed thickness), seed weight traits (single-seed weight and 100-seed weight), and oil content were measured in the laboratory for each lot of sample seeds from a given individual.

Data analysis

The data of each trait were tested for normality and homogeneity. However, the data on tree morphological traits failed to satisfy the assumption of homogeneity of variance, hence were transformed by the square-root transformation. ANOVA was performed, using the one-way procedure, and a test of significance was made by the least significant difference method (LSD), between and within the families (Gomez and Gomez, 1984).

Physic nut is cross-pollinating species, and comparisons should be made within families rather than lines or single trees (Heller, 1996). This allows the variation within families to be minimized, and maximized among families (Zobel and Talbert, 1984). In the present study, the assumption was that trees exhibit high similarity than with individuals that are within the family or plot, rather than with those outside. Each plot of the 6 sites was considered as a unique genotype or family, and used to estimate genetic variation across the population. Then, a mean comparison of families was performed, by the least significant difference method. For the ANOVA and LSD, Minitab 13 for Windows was used (Minitab, 2000).

First, the partitioning of the total phenotypic variances was done for a single-trait analysis, using a simple model suggested by Kumar *et al.* (2006):

$$Y_{ij} = \mu + f_i + e_{ij} \qquad \textit{Equation 1}$$

Where, Y_{ij} is the phenotypic value for the j^{th} individual in the i^{th} sample family for a given trait; μ is the general mean; f_i is the random effect of i^{th} family; e_{ij}

is the random within-family effect (i.e. residual error resulting from segregation, dominance, and environmental contributions).

Variances of the phenotypic, genotypic, and environmental components were then estimated according to the method of Kung and Bey (1978). The expected mean squares were used to estimate each component of variance, as shown in Table 1.

Table 1. Equations for components variances estimation

Components	MS	EMS	variances *formula*
Genetic	MS_f	$Ve + rV_g$	$V_g = \frac{MSf - V_e}{r}$
Error	MS_e	V_e	$Ve = MS_e$

Where, MS_f is Mean square among families, MS_e is Mean square within families, V_g is genotypic variance, V_e is environmental or error variance and r is replication.

The coefficients of variation for genotypic *(GCV)* and phenotypic components (*PCV*) were then estimated from their respective standard deviations, using the following two equations, according to the method of Mahadevan, *et al*. (1999);

$$GCV = \frac{(\sigma_g^2)^{\frac{1}{2}}}{Mean} \times 100$$

Equation 2

$$PCV = \frac{(\sigma_p^2)^{\frac{1}{2}}}{Mean} \times 100$$

Equation 3

Where, σ^2_g is a genotypic variances and σ_p is a phenotypic variances.
The family broad-sense heritability (h^2) of each trait was estimated from the *F*-value according to the following formula (Kung and Bey, 1978),

$$h^2 = 1 - 1/F$$

Equation 4

The responses to selection of the local population investigated were determined using genetic advance (*GA*) and genetic advance as percentage of mean (*GAM*). The expected genetic advance (*GA*) for each character (at 5%

selection intensity) was computed using equation that was suggested by Johnson *et al.* (1955).

$$GA = i \times h^2 \times \sigma_p \qquad \textbf{Equation 5}$$

Where, i is constant selection differential (i = 2.056) at 5% selection intensity, σ_p is phenotypic standard deviation on mean basis, and h^2 is heritability in the broad sense.

Genetic advance as percentage of mean (*GAM*) was then calculated, to compare the extent of predicted genetic advance of different characters after standardization with their mean, according to the method suggested by Johnson *et al.* (1955). It was calculated as follow;

$$GAM = \frac{GA}{\overline{X}} \times 100 \qquad \textbf{Equation 6}$$

Where, $\overline{X}$ stand for the population mean value of the character.

The Pearson correlation coefficient was calculated among tree traits, namely number of capsules per tree, seeds/tree, seed length, seed breath, seed weight, 100-seed weight, and oil content, according to Yao and Mehlenbacher (2000). The correlation coefficient matrix and significance tests were calculated with Minitab 13 for Windows (Minitab, 2000).

Results and Discussion

Analysis of variance

Variability among the 18 families was estimated from a family-based estimation of mean, ranges, standard deviation, and coefficient of variation for each of the nine traits. Their estimated value is presented in Table 2. In addition to these parameters, the maximum and minimum measurements of these traits with their respective location, based on individual trees, are shown in Table 3.

The local population of physic nut was found to produce on average 210 capsules and 631 seeds per singletree. The number of seeds per tree varied between 192–1124 (Table 2). The maximum observations for all tree morphological traits were found at Kemise, and the minimum at Shewa Robit (Table 3). The mean values of seed length, seed breadth and seed thickness of the local physic nut families from the study area were about 17.17 mm, 8.2 mm and 10.50 mm, respectively (Table2).

The average seed weight and 100-seed weight were about 0.60 g and 60.17 g (Table 2). The individual based seed weight and 100-seed weight varied between 0.35–0.8 g and 42–78 g, respectively (Table 2). The maximum values for seed weight traits were found at Shewa Robit (Table 3).

The oil content of the study population was on average 29.19% by weight for moisture-free seed. This varied from 22.40% at Chefa Robit to 34.40% at Shewa Robit (Table 2).

Table 2. Family-based estimate of mean, range, standard deviation, and coefficient of variation of traits

Traits	Ranges	Mean	SD	C.V%
No. branch/tree	16.00–54.00	35	9.62	27.72
No. capsule/tree	64.00–375.00	210	69.40	32.99
No. seed /tree	192.00–1124.00	631	208.20	33.00
Seed length (mm)	16.700–17.90	17.17	0.35	2.03
Seed breadth(mm)	7.90–8.60	8.21	0.23	2.78
Seed thickness(mm)	10.10–10.90	10.50	0.23	2.22
Seed weight (g)	0.53–0.71	0.60	0.05	8.03
100 seed wt(g)	52.53–70.16	60.17	4.89	8.14
Oil content (%)	22.40–34.40	29.19	2.26	7.75

Generally, the analysis of variance among 18 families of local physic nut for all traits showed significant differences ($p < 0.01$) at the minimum level. The ANOVA output for morphological and seed traits, as well as oil content, is shown in Table4. All of the tree morphological traits of the 18 families of the local physic nut population were different at ($p = 0.01$). The seed-size traits of the families were also significantly different. The 100-seed weight and oil content also differed highly significantly (Table 4).

Table 3. Observed value of each trait on individual sample trees

Traits	Min.	Location	Max.	Location
No. Branches/tree	2.80	Shewa Robit	84	Kemise
No. capsules/tree	27.80	Shewa Robit	534	Kemise
No. seeds /tree	83.00	Shewa Robit	1605	Kemise
Seed length (mm)	14.10	Senbete	19.0	Bati, Chefa Robit
Seed breadth (mm)	6.90	Harbu	9.5	Chefa Robit
Seed thickness (mm)	9.30	Kemise	11.3	Senbete
Seed weight (g)	0.35	Kemise	0.80	Shewa Robit
100-seed wt (g)	42.00	Chefa Robit	78.0	Shewa Robit
Oil content (%)	22.40	Chefa Robit	34.4	Shewa Robit

Table 4. Estimate of mean squares of families and error

Traits	Among families	Within family	Test	
	MSF	MSE	F Calc.	P Value
No. Branches/tree	8.12	3.4206	2.38**	0.003
No. capsules/tree	595.32	229.6718	2.59**	0.001
No. seeds /tree	1785.97	689.0153	2.59**	0.001
Seed length (mm)	0.0109	0.0054	2.02*	0.014
Seed breadth (mm)	0.0047	0.0025	1.88*	0.023
Seed thickness (mm)	0.0049	0.0016	3.06**	>0.0001
Seed weight (g)	0.0209	0.0069	3.03**	>0.0001
100-seed wt (g)	215.66	21.1770	10.18***	>0.0001
Oil content (%)	46.12	3.0627	15.06***	>0.0001

As was mentioned above, yield is a function of a number of traits, which directly or indirectly contribute to the overall yield of the crop. For the development of high-yielding varieties, a thorough knowledge of the existing genetic variation for yield and its components is required (Wani and Khan, 2006). For this reason, the investigation of tree morphological traits was designed so that they could be studied as a yield component.

The present study found that the local population of *J. curcas* exhibits considerable variation in all tree morphological traits. This indicates the presence of sufficient genetic variability for effective selection to identify superior genotypes.

The results were similar to those of other reports on *J. curcas* (Heller, 1996; Ginwal *et al.,* 2004; Pant *et al.,* 2006). These reports suggested that the causes of such variations in *J. curcas* were genetic and environmental influences. Among the 11 provenances of *J. curcas*, Heller (1996) found a significant difference in the number and weight of capsules per shrub, and the number and weight of seeds per shrub. Similarly, studies at Hisar, Bangalore, and Sardar Krushinagar in India revealed considerable variation in plant height, branches per plant and seed yield per plot (Heller, 1996). From these results, the genetic influences on the tree morphological traits of the species were inferred.

Another Indian study (Pant *et al.,* 2006) reported that the number of branches/tree, the number of fruits or capsules/tree and the number of seeds/tree differed significantly when tested over an altitudinal gradient. That study demonstrated the effect of site conditions on the variation exhibited by the species. Hence, variation in the present study might have arisen from either of the two causes.

Even if the trend and degree of variability were similar to those in other reports, the actual measured values were different. Evidently, the comparison of values from different germplasm, site conditions, age, and management is difficult, and the results seldom agree. Thus, it was difficult to compare the present study with other reports, because of the differences in estimation technique, growing conditions, age and definition of branch that were used. The present study was based on unselected, non-experimental units that are assumed to be older than five years but age; in the other literature, age was less than five years. Other reasons for the discrepancy in the mean values may be inherited variation, location variation, sampling error or random error. The present study was based entirely on a survey of domesticated, existing hedges and live fences, which had been planted for different purposes and under different conditions. However, the observed variability among the 18 families is indicative of genetic variability that could give a lead in the breeding of physic nut.

Study of the seed morphology of natural populations is often considered a useful step in the study of their genetic variability (Kaushik *et al.,* 2007). Seed size and thickness differed significantly among families. The results for seed length, seed thickness, and seed breadth in the present study were similar to those in the Haryana population reported by Kaushik *et al.* (2007).

The 18 families were highly significantly different in 100-seed weight and oil content, indicating that the existing variation would allow selection for larger seed size and higher oil content. Kaushik *et al.* (2007) showed that there was significant variability for 100-seed weight and oil content among 24 accessions of physic nut from Haryana, India. Similarly, Ginwal *et al.* (2004) found that seed sources of physic nut varied significantly with respect to seed weight and oil content in whole seeds and in the kernel. Heller (1996) reported that the weight of seeds per shrub and 1000-seed weight were significant in Senegal.

The mean oil content, 28%, obtained in this study was lower compared to reported results elsewhere, *e.g.* Kaushik *et al.* (2007) 33%, Ginwal *et al.* (2004) 36%, and Sunil *et al.* (2007) 35–40%. This could derive from the fact that the present study was based on unselected non-experimental units, *i.e.* on relatively untended hedges, or be due to the inclusion of families with a low, oil content. On the other hand, the oil content is environmentally influenced, particularly by moisture and soil fertility.

In general, in view of the fact that the local population of *J. curcas* in eastern Amhara grows under varying site conditions, it might have experienced marked differences in selective pressure, or might have differed in its genetic background, in consequence of its hasty introduction. The observed variation confirms the potential of the local population of *Jatropha* to produce a high-yielding genetic material through selection.

Estimation of the Components of Variance

The estimates of genotypic, phenotypic, and environmental variances, together with the genotypic and phenotypic coefficient of variation of nine characters, are shown in Table 5.

Phenotypic and Genotypic Variances

Generally, Table 5 shows that the phenotypic variance was higher than the genotypic variance for all traits, however, the genotypic variance for 100-seed weight and oil content showed relatively little difference from the phenotypic variance. Phenotypic and environmental variances revealed that genotypic variances were high for 100-seed weight and oil content than the rest traits (Table 5). These two traits score higher for genotypic variance than for their environmental variances, and slightly lower than for their phenotypic variation (Table 5). Genotypic and phenotypic variances were high for number of seeds per tree (121.884 and 810.899), and their minimum was for seed breadth (0.000256 and 0.003, respectively). Genotypic, environmental, and phenotypic variances of oil content were 4.784, 3.063 and 7.846, correspondingly (Table 5).

A tree-breeding strategy largely depends upon the extent of variability in the base population, which is measured by various parameters, viz. genotypic and phenotypic variances, and the genotypic and phenotypic coefficient of variation (Ginwal *et al.*, 2004). The higher phenotypic variances in all traits of the study, excluding 100-seed weight and seed oil content, indicatd that a larger proportion of the phenotypic variance was contributed by the environmental variance. However, 100-seed weight and seed oil content traits had relatively greater genotypic than environmental variance. This implies that the performance of different sources of *J. curcas* for these traits can be tested with minimum cost and time. In support of this, Miller *et al.* (1957) noted that for those traits for which the genetic variance is larger relative to the environmental variance, accessions may be evaluated adequately by testing a few replicates, location and years. By contrast, they also suggested that traits with high environmental variances should be tested in a sufficient number of replications, years, and locations. The results obtained in the present study were similar to those reported by Ginwal *et al.* (2004).

In this study, the estimated genetic variance for all traits was smaller than the phenotypic, indicating that the observed variation was largely contributed by environmental variation of external factors, such as growing conditions, age, sampling error and random error. These might arise from the difference between the experimental units situated on different sites. On the other hand, the method used to partition the components of ANOVA was a simple linear model, which considered genetic variation as one factor and the cumulative external factors as error. So, the lower genetic variance does not imply that the genetic effect on the local population of physic nut is minimal absolutely, but as compared to the other cumulative non-genetic factors, including statistical errors, it was lower.

In general, high phenotypic and genotypic variances in the quantitative traits of the local population indicated better chances for selection to be successful.

Genotypic and Phenotypic Coefficient of Variation

The magnitude of genetic variation expressed by different tree morphological, seed size, seed weight and oil traits could be judged through the value of their respective coefficient of variation. In Figure. 2, it is shown that the magnitude of the *PCV* was higher than the corresponding genotypic ones for all characters. The overall variation in tree morphological traits were higher than the rest traits and seed size traits were found with the least range of variation, among the local families of physic nut in eastern Amhara. When a separate comparison of each trait considered, the highest *PCV* (35.76%) were resisted by two traits, i.e. number of seeds/tree and number of capsule and the least *PCV* (4.26%) was by seed thickness (Table 5). The genetic coefficient of variation values were between 1.81% (seed thickness) and 14.88% (number of seeds/tree). The *GCV* and *PCV* value for oil content were 7.94% and 9.6%. Generally, the difference between the *PCV* and *GCV* of oil content was lowest, followed by 100-seed weight, and the maximum value of this difference was observed on seed breadth.

The genotypic coefficient of variation measures the range of genetic variability shown by the plant trait, and helps to compare the genetic variability present in various traits. The observed difference in the magnitude of variation within a given trait might arise from different reason. Regarding the tree morphological traits, the high level of variation might arise from the a exposure and nature of the traits to human or environmental effects, as mentioned above the study material was based on already existing farmer’s hedge which grow under different management and growing conditions.

In this study, the genotypic coefficients of variation are comparatively lower than phenotypic coefficient of variation for all the traits. Similar result were reported by Ginwal *et al.* (2004), for the number of branch/tree, seed weight traits and oil content of local physic nut of India. The except for oil content, the result of this study on seed size and weight trait is in agreement with the results of Kaushik *et al.* (2007). The PCV and GCV oil content of that study was reported as equal which deny the effect of environment on that trait, this could arise either the statistical model used for partitioning the components of variances during analysis of variances or the efficiency of the oil extraction technique used in the experiment.

Table 5. Genotypic, environmental, phenotypic variances and genotypic and phenotypic coefficients of variation in 18 families of physic nut

Traits	Variances			CV %	
	V_g	V_e	V_p	GCV	PCV
No. of branches/tree	0.52	3.42	3.94	13.02	35.76
No. of capsules/tree	40.63	229.67	270.30	14.88	38.37
No. of seeds /tree	121.88	689.02	810.90	14.87	38.37
Seed length (mm)	0.001	0.0050	0.006	1.84	4.51
Seed breadth (mm)	0.0003	0.0025	0.003	1.95	6.68
Seed thickness (mm)	0.00036	0.0019	0.002	1.81	4.26
Seed weight (g)	0.002	0.007	0.008	7.41	14.81
100-seed wt (g)	21.609	21.177	42.786	7.73	10.88
Oil content (%)	4.784	3.063	7.846	7.49	9.60

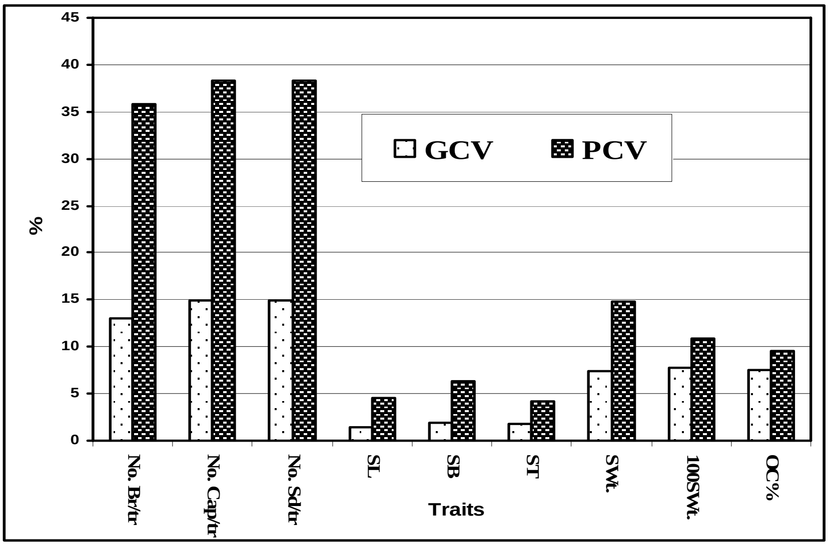

Figure 2. Graphical presentation of the GCV and PCV of nine traits of local Jatropha curcas families.

Genetic Parameters

Heritability

The genetic coefficient of variation provides information on the genetic variability present in various quantitative characters, but it is not possible to determine the amount of the variation that was heritable from only the genotypic coefficient of variation. The genetic coefficient of variation, together with heritability estimates, would give the best picture of the amount of advance to be expected from selection (Burton, 1952). Thus, the heritable portion of the variation was elucidated with the help of heritability estimates.

The broad-sense heritability estimates of all traits of the study were from moderate to high. Among the nine traits, the broad-sense heritability (h^2) was highest (0.93) for oil content, followed by 100-seed weight (0.90), and the lowest recorded was for seed thickness (0.47) (Table 6). Heritability is described as an important tool in selecting superior phenotypes (plus trees), based on the phenotypic performance of quantitative characters (Vasudeva *et al.,* 2004). Heritability is considered to be high when the value is between 0.70–0.99 and moderate when it is 00.4–0.7 (Gomes *et al.*, 2003), coefficients of variation in 18 families of physic nut. A similar report of higher heritability for 100-seed weight and oil content was presented by Kaushik *et al.* (2007).

If the heritability of a character is very high (> 80%), selection for such a character should be fairly, easy owing to the close correspondence between the genotypes and the phenotypes which arises from a relatively smaller contribution of the environment to the phenotype (Singh, 1999). For a character with low heritability (< 40%); however, selection may be considerably more difficult or virtually impractical, owing to the masking effect of environment on the genotypic effects (Singh, 1990). Depending on this fact, in the present study, it can be safely concluded that the selection of genotypes based on 100-seed weight and oil content would be more satisfactory in the case of physic nut.

Genetic Advance

To predict the selection effects precisely, heritability accompanied with genetic advance is more useful than heritability alone (Johnson *et al.,* 1955). Therefore, genetic advance was also computed as percentage of mean, to predict the gain from a selection of superior genotypes from the local population of physic nut, assuming for 5% selection intensity. The results (Table 6) indicated that maximum genetic advance as percentage of mean of 48.45% followed by 48.44% was recorded in number of seeds/tree and number of capsule/tree, respectively. The minimum of 4.67% genetic advance as percentage of mean was obtained for seed length. Oil content had a promise of 18% of gain over the mean.

The ultimate aim of most variability or screening studies is to provide a framework for future selection; the present study therefore also attempted to provide the probable genetic gain, for future selection is to be conducted on the population. Johnson *et al.* (1955) indicated that the estimate of heritability and genetic advance should always be considered simultaneously, because high heritability is not always associated with high genetic advance. The utility of heritability estimates increases when they are used in conjunction with genetic advance, expressed as a percentage of the mean (Johnson *et al.*, 1955; Allard, 1960). As Panes (1957), when there is high genetic advance coupled with high to moderate heritability would give better scope for selection. In addition, the author noted that, the association of high heritability with high genetic advance is due to additive gene effect.

In the present study, moderate heritability of the numbers of branches/tree, the number of capsules/tree and the number of seeds/tree (Table 6) coupled with high genetic advance indicates the presence of additive gene effects. This result was in agreement with the result of Ginwal *et al.* (2004) on tree growth traits of different physic nut seed in central India. This type of genetic effect and the wide range of variation of tree morphological traits of local physic nut population offer good scope for genetic improvement of this species and their improvement can be done through mass selection.

Next to above the traits, 100 seed weight have shown relatively high genetic *GAM* (20.17%) but higher heritability (90%) than those traits. This has clearly shown that a considerable portion of variance of the trait is additive. This signifies that these traits are under strong genetic control and good amount of heritable additive genetic component can be exploited for further selection. A similar report of higher heritability and *GAM* for seed weight trait was presented by Ali *et al.* (2003).

Although, the highest heritability (93%) was computed for the seed oil content, its *GAM* (< 20%) was relatively lower than the tree morphological and seed weight traits, high heritability and again than the above mentioned traits. In general sense, high heritability (broad-sense) may be due to non-additive gene action, however, it shall be reliable only if accompanied by high genetic gain (Rawat and Nautiyal, 2007). For this reason, a selection based on this trait may not provide with an improved performance of progenies.

In the other side, the seed size traits revealed with very low *GAM* of 4.68–6.43% (Table 6). So that the traits are not expected to show high genetic advance and it can be judged to have more of non-additive genetic effects than additive genetic effects (Roy *et al.*, 2004). A moderate heritability for characters, combined with low *GCV* and genetic advance as percent of mean indicates the importance of both additive and non-additive gene action for these characters (Paulsamy *et al.,* 2007).

In general, the findings of the present investigation on the genetic advance of seed size traits and seed oil content of physic nut are in congruous with that of Kaushik *et al*. (2007).

Table 6. Heritability, genetic advance, and genetic advance as a percentage of the mean for 18 physic nut families

Traits	h^2	GA	GAM
No. of branches/tree	0.58	2.36	42.58
No. of capsules/tree	0.61	20.76	48.44
No. of seeds /tree	0.61	35.96	48.45
Seed length (mm)	0.50	0.08	4.68
Seed breadth (mm)	0.47	0.05	6.43
Seed thickness (mm)	0.67	0.06	5.90
Seed weight (g)	0.67	0.12	20.40
100-seed wt (g)	0.90	12.13	20.17
Oil content (%)	0.93	5.38	18.42

Coefficients of Phenotypic Correlation

The Pearson correlation coefficients (*r*) among tree morphological, seed-size, seed-weight, and oil traits with their level of significance are presented in Table 7. There was a high correlation among tree morphological traits, with a high significance level. There was no significant correlation between tree morphological traits and all seed traits. All seed-size traits were very highly significant and positively correlated with seed weight and 100-seed weight. The oil content had a highly significant correlation with 100-seed weight, and the test showed that it had no significant correlation with seed breadth alone. The correlation between 100-seed weight, all seed-size and seed-weight traits was very highly significant.

The seed breadth was correlated significantly with all seed-size and seed-weight traits. Seed weight was correlated highly significantly with all seed-size traits and seed weight, with high correlation coefficients. It had also a highly significant correlation with oil content with a moderate ‘r’. There were no significant correlations between oil content and the number of capsules/tree, the number of seeds/tree and seed breadth. The correlation between oil content and seed-weight traits was highly significant, with moderate strength. The 100-seed weight had the largest positive correlation with oil content, with very high significance, followed by seed weight with oil content.

The nature of inter-trait correlations may enhance or retard the selection progress. Therefore, analysis of the correlation between yield and yield components is essential in determining the selection criteria (Yücel *et al.*, 2006). As oil production is the prime goal of physic nut cultivation, at least for the current period, any trait that will maximize oil yield is of primary concern on tree improvement work on this species.

Oil content/seed is a direct contributor to the overall oil yield of the crop. In the present study, the oil content had a highly significant, positive correlation with seed weight (r = 0.315) and 100-seed weight (r = 0.463). A similar result was reported by Kaushik *et al.* (2007) regarding the correlation between seed weight and oil content. Larger seeds in castor, rapeseed, linseed and niger result in a higher oil content from a similar genetic background (Getinet and Nigussie, 1997; Getinet *et al.,* 2008). This indicated that selection for larger seed size or weight would lead to higher oil content. This is because large seeds have a relatively higher amount of embryo and endosperm where oil is deposited, as compared to smaller seeds.

In addition, a significant positive correlation was found for the trait oil content, with seed thickness and seed length. As regards the correlation between seed length and seed oil content, a significant negative correlation has been reported, which is the opposite of the results of the current study. The present paper cannot explain the reason for this contradiction, other than in terms of statistical error. Rather, the correlation with oil content was non-significant and very weak; surprisingly, the results of Kaushik *et al.* (2007) are similar.

In general, tree morphological traits were not correlated with all seed traits, and showed a significant, negative correlation with the number of branches/tree and oil content. This might be a result of competition for nutrients and photosynthates between vegetative growth and the production of additional seed, as the number of branches increases.

Table 7. Estimate of Phenotypic Correlation coefficients

Traits	No. Branches /tree	No. Capsules/tree	No. Seeds/tree	Seed Length	Seed Breadth	Seed Thickness	Seed weight	100-seed Wt.
No. capsules /tree	0.777***							
P-value	*<0.0001*							
No. seeds /tree	0.777***	0.999***						
P-value	*<0.0001*	*<0.0001*						
Seed length	0.026	0.049	0.049					
P-value	*0.740*	*0.534*	*0.534*					
Seed breadth	0.093	0.143	0.143	0.506***				
P-value	*0.241*	*0.069*	*0.069*	*<0.0001*				
Seed thickness	-0.009	0.113	0.113	0.471***	0.444**			
P-value	*0.911*	*0.154*	*0.154*	*<0.0001*	*<0.0001*			
Seed weight	0.031	0.062	0.062	0.661***	0.617***	0.563**		
P-value	0.697	0.433	0.433	<0.0001	<0.0001	<0.0001		
100-seed wt	-0.059	0.039	0.039	0.343***	0.331***	0.35***	0.576***	
P-value	*0.456*	*0.619*	*0.619*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*	
Oil %	-0.227*	-0.116	-0.116	0.154*	0.099	0.161*	0.315***	0.463***
P-value	*0.004*	*0.141*	*0.141*	*0.050*	*0.212*	*0.040*	*<0.0001*	*<0.0001*

*Significant, ** highly significant, and *** very highly significant.*

Conclusion

The existing population of physic nut exhibits a considerable degree of variation among families or sub-populations grown at different sites in Eastern Amhara. The larger variation between families than within families in this study, leads to the conclusion that there is a good opportunity for selection and breeding among physic nut populations.

The values and measurements observed in this study for seed weight and oil content were relatively lower than reported elsewhere, probably due to environmental effects. The samples were taken from hedges, not from experimental plots or commercial plantations; hence, the lower values are not too surprising. Nevertheless, the range of oil content observed in this study is sufficient to initiate selection of superior genotype with maximum seed oil content.

On the other hand, the heritability of most characters was moderate, except for oil content and seed weight. The heritability observed for oil content and seed weight was comparable with available reports on the same spices and much higher than those reported elsewhere in other oilseeds. The higher heritability of oil content and seed weight may indicate that selection for oil content could be successful. However, this was not substantiated by the higher value of genetic advance as a percentage of the mean. Therefore, direct selection for oil content may be difficult and even impossible, as is known from other oilseeds. Fortunately, one of the most economically valuable traits, oil content, was highly and positively correlated with seed size and weight, so that a selection for larger seed size and weight can result in higher oil contents. This type of indirect selection is also observed other oil seed bearing species like *Ricinus communis*, *Helianthus annuus*, *Brassica napus,* and *Nigella sativa*.

Oil production is the most important goal of physic nut cultivation; the economics of the production is also determined by seed yield equivalent to oil content of a planting material. The seed yield of physic nut depends on the number of female flowers/tree, so, during selecting genotype for commercial plantation, this type of trait should be considered in addition to the oil content.

The observed variation in tree and seed traits and oil content is very encouraging for the selection of high-yielding provenances of physic nut for future plantation. Physic nut is non-edible, is adapted to marginal lands and hence does not compete with food production, which makes it an excellent candidate for biodiesel. However, higher economic yields, both in seed and oil content, are important. Therefore, the selection of high-yielding provenances, with oil contents of well over 40%, is required before any commercial plantation is initiated.

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Annex 1. List of family mean, LSD and mean comparing prefixes

Location	Family	No.branches /tree		No.capsules /tree		No.Seeds /tree		SL		SB		ST		SWt.		100-SWt.		Oil%	
Shewa Robit	SR01	16	a	64	a	192	a	17.4	bcd	8.1	abcde	10.5	abcdef	0.61	bcde	60.67	defgh	31.7	ijk
Shewa Robit	SR02	28	abcd	193	bcd	579	bcd	17.9	d	8.4	bcde	10.9	g	0.71	f	70.16	j	32.8	k
Shewa Robit	SR03	35	bcde	220	bcd	659	bcd	17.6	cd	8.4	cde	10.7	efg	0.67	ef	66.36	ij	31.8	jk
Senbete	SB01	35	bcde	186	bc	559	bc	17.3	abcd	8.5	e	10.6	cdefg	0.63	bcde	62.78	fghi	27.3	b
Senbete	SB02	19	ab	161	abc	483	abc	17.3	abcd	8.2	abcde	10.7	efg	0.60	abcde	60.41	defg	31.5	hijk
Senbete	SB03	37	cdef	262	bcde	786	bcd	17.0	abc	8.3	abcde	10.8	fg	0.64	cdef	64.15	ghi	29.7	efg
Chefa Robit	CR01	45	def	175	abc	526	abc	16.7	a	8.1	abcd	10.1	a	0.53	a	52.84	a	27.6	bc
Chefa Robit	CR02	40	cdef	208	bcd	622	bcd	16.9	abc	8.2	abcde	10.3	abcde	0.57	abc	56.15	abc	24.8	a
Chefa Robit	CR03	34	bcde	204	bcd	613	bcd	17.1	abc	8.2	abcde	10.7	efg	0.60	abcde	59.28	cdef	30.7	ghij
Kemise	K01	43	cdef	281	cde	842	cde	17.5	cd	8.6	e	10.5	abcdefg	0.64	cdef	64.90	hi	30.0	fgh
Kemise	K02	36	bcdef	222	bcd	665	bcd	17.3	abcd	7.9	abc	10.2	abcd	0.57	abc	56.67	abcd	26.9	b
Kemise	K03	54	f	375	e	1124	e	17.6	cd	8.5	de	10.7	efg	0.66	def	65.76	i	29.0	cdef
Harbu	H01	28	abcd	181	abc	541	abc	16.7	a	8.1	abcd	10.3	abcd	0.59	abcd	59.01	cdef	30.8	ghijk
Harbu	H02	49	ef	312	de	937	de	16.8	ab	8.1	abcd	10.2	ab	0.57	abc	57.71	bcde	28.4	bcde
Harbu	H03	34	bcde	259	bcde	776	bcd	17.3	abcd	8.5	de	10.7	efg	0.62	bcde	61.46	efgh	30.1	fghi
Bati	B01	27	abc	152	ab	457	ab	16.7	a	7.9	a	10.4	abcde	0.58	abcd	57.22	bcde	29.3	defg
Bati	B02	31	abcde	163	abc	490	abc	16.8	ab	7.9	ab	10.2	abc	0.56	ab	54.39	ab	27.8	bcd
Bati	B03	32	abcde	168	abc	504	abc	17.2	abcd	7.9	a	10.5	bcdefg	0.53	a	52.53	a	25.2	a
	mean	35±20.76		210±141.2		631±423.7		17.2±0.8		8.2±0.5		10.5±0.439		0.6±0.09		60.1±6.46		29.2±2.76	
	LSD	18		121		363		0.7		0.5		0.4		0.08		4.25		1.6	

Effects of Germination Sites on Germination Percentage, Germination Energy and Germination Value of Lowland Bamboo Seeds

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Introduction

Ethiopia possesses considerable bamboo resources in Eastern Africa in terms of area coverage. There are two indigenous species of bamboo in Ethiopia: the highland or African alpine bamboo (*Yushania alpina* (K. Schum.)) synonym *Arundinaria alpina* (K. Schum.) and a monotypic genus lowland bamboo (*Oxytenanthera abyssinica* (A. Rich.) Munro) (Phillips, 1995; Embaye, 2000). These species are indigenous to Ethiopia and endemic to Africa, which is confined to the Sub-Saharan Region, but not outside the African continent (Embaye, 2000). They are widespread in Ethiopia covering about one million ha, *i.e.*, about 7% of the world total and 67% of the African bamboo forest area (Embaye, 2000).

O. abyssinica widely distributed in eastern and southern Africa mainly Ethiopia, Malawi, Zimbabwe, and Zambia covering 700,000-850,000 ha area of land (Nune, 2001; UNIDO, 2009). While in western Africa, it is located in some parts of Ghana and Senegal. However, natural populations are found all over the African continent (UNIDO, 2009). The species is found in Savanna woodland, favoring river valleys, often forming extensive stands at the altitudes ranging from 1200-1800 m above sea level (Phillips, 1995). Its annual rainfall is ranging from about 700-1000 mm, which is concentrated over a period of three to four months with the mean annual temperature of above 30 ^{o}c (UNIDO, 2009). This species is widely distributed in lowland regions of western and northwestern parts of Ethiopia (Nune, 2001) in Tigray, Gonder, Gojam and Welega Regions (Phillips, 1995). The species is easily adaptable to poor soils and provide as a buffer zone for desert areas (UNIDO, 2009).

In Ethiopia, *O. abyssinica* is commonly known by various local names in different areas with respect to their languages. Accordingly, it is known as SHIMEL in Amharic; ARKAY in Amharic/Tigray; T'AMIA/SANKARA in Wellayita (Kelecha, 1980) and SHIMALLA in Affan Oromo (UNIDO, 2009). Bamboo resources have a considerable potential to socio-economic development of the local people; environmental protection such as adaptation to global climatic change through carbon sequestration; biodiversity conservation and wider ecological adaptation (Embaye, 2002, 2004; Kelemwork, 2011). But, currently the bamboo resource of Ethiopia is underutilized and has been neglected by development practitioners. As a result, its use is limited to hut construction, fencing, production of handicrafts, furniture and other household utensils (Kelecha, 1980). Due to this reason, there is indiscriminate resource depletion by different human activities and mass flowering and subsequent death of lowland bamboo resource. Besides, the low viability of seeds and hence poor storage characteristics, flowering at longer intervals and limited availability of seeds is the practical problem in bamboo large-scale propagation using seeds (Gilles and Amy (1980) cited in Hunde *et al.* (2005); Kigomo (2007).

Materials and Methods

Study site

The seeds of *O. abyssinica* used for the present study were collected from Pawe Wereda, Metekel Zone of Benishangul-Gumuz Regional State, Ethiopia. It is located at 575 km away from Addis Ababa.

Seed collection

Mature seeds of *O. abyssinica* were collected from 25 clumps of healthy and middle-aged bamboo stands. The collected fresh seeds then put into perforated plastic bags and safely transported to Forestry Research Center (FRC). Seeds processed and stored in cold room at a temperature of $+5^0$c to maintain the viability of seeds and prevent from insect attack.

Purity analysis (PA), Moisture content (MC) and Seed weight per kg of seeds

The purity analysis, moisture content and seed weight per kg of *O. abyssinica* seeds were determined at FRC laboratory following the methods by FAO (1985).

Effects of germination sites on seed germination percentage or capacity (Experiment I)

The effect of germination sites on seed germination percentage or capacity was assessed by conducting seed germination tests at three various germinating sites, *i.e*., laboratory, greenhouse, and seedbed. Accordingly, using Completely Randomized Design (CRD) at laboratory 100 seeds in five replications of 20 seeds per petri-dish filled with moist filter paper were sown. At seedbed 400 seeds in 8 replications of 50 seeds per raw on seedbed were sown. Whereas, at green house 200 seeds in 6 replications of 30 seeds per petri-dish and the remaining 1 replication of 20 seeds per petri-dish filled with forest soil and sand were sown. Following this, daily watering of the seeds was done at each site until germination completed. Daily germination of seeds was recorded until germination completed and all the recorded germinated seeds were counted and removed to avoid double counting.

Effect of storage periods on seed viability or longevity (Experiment II)

To investigate whether storage periods of *O. abyssinica* seeds affect seed viability or longevity, seed germination tests were carried out starting from freshly collected seeds and then within 4 months of intervals until 44 months of storage periods at cold room for laboratory tests in a similar procedure as described in section 2.4. However, the tests were conducted for 32 months of storage periods for green house and seedbed because of the shortage of seeds. So, for the comparison of the three germination sites only 32 months of storage periods was considered.

Effect of germination sites on germination patterns of O. abyssinica seeds (Experiment III)

To study the effect of germination sites on germination pattern of *O. abyssinica* seeds, seed germination test at three various germinating sites, *i.e*., laboratory, green house, and seedbed were conducted from the first to the 4th weeks. The germination test was carried out in a similar procedure as described in section 2.4.

Effect of germination sites on germination energy and germination value of O. abyssinica seeds

The effect of germination site on germination energy and germination value of *O. abyssinica* seeds was investigated by calculating the germination energy and germination value of seeds following the methods by FAO (1985).

Data analyses

Collected data were analyzed and evaluated by using percentages and graphs. In addition, the statistical significance was determined by one-way Analysis of variance (ANOVA) or Chi-Square ($\chi 2$) test at 95% confidence interval and multiple comparison of Least Significance Difference (LSD) to show real significance difference among the treatments using SPSS Version 20.0 Computer Software Programme.

Results and Discussion

Purity analysis test

The purity analysis of *O. abyssinica* seeds indicated that its percentage was 78%. That means, the seed is said to be pure seed.

Moisture content test

The percentage moisture content of *O. abyssinica* seeds from the average of the two samples found to be 4-7% for storage in cold room at about $+5^0$C.

Seed weight test

The overall seed weight test after purity analysis indicated that there are 8,393 seeds contained within one kg of pure *O. abyssinica* seeds.

Effects of germination site on seed germination percentage or capacity

According to the overall result output, the three various germinating sites, *i.e*., laboratory, greenhouse, and seedbed showed 70-83%, 52.5-74%, and 19-66% germination percentage, respectively (Figure. 1). Therefore, the germination percentage of *O. abyssinica* seeds at three major germination sites indicated that laboratory recorded the highest germination percentage of 83%, while the lowest percentage of 19% was observed at seedbed. The statistical test of ANOVA showed that no significant difference ($F=0.794$, 1.389 and 0.543, $P<0.05$) between germinating sites (at laboratory, green house and seedbed), respectively. Such a wider range of variation in germination percentage might be due to differences in environmental factors including temperature and moisture variation. Likewise, Hartmann and Kester (1983) reported that for a successful germination of a viable seed, favorable internal conditions of the seed and environmental factors are very crucial.

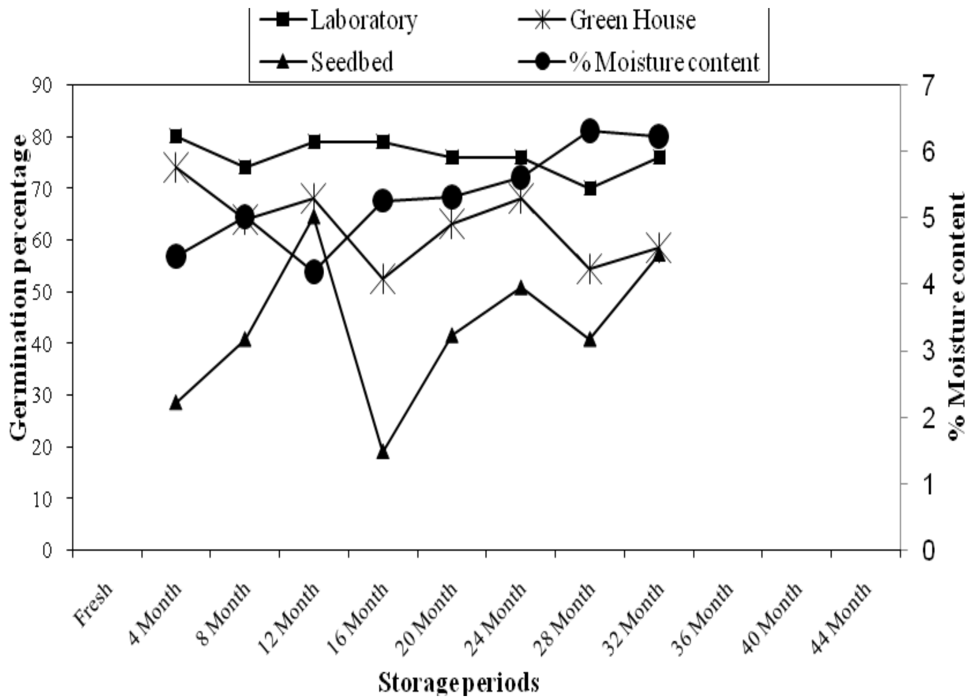

Figure 1. Germination percentage of *O. abyssinica* seeds at laboratory, green house and seedbed under different storage periods.

Effect of storage periods on seed viability or longevity

The germination percentage of *O. abyssinica* seeds recorded at the end of the experiment ranged between 19% and 83% within 44 months of storage in cold room within 4-7% of moisture content. The seeds germination test was carried out without undertaking any type of seed pre-sowing treatment. This revealed that the problem of viability and presence of hard seed coat were not important factors in controlling both the germination percentage and germination period of *O. abyssinica* seeds for this particular study, unlike seeds of *Podocarpus falcatus* (Negash, 1992 , 1993). Thus, the seeds generally had longer variability as well as survival value and hence stored for longer periods, *i.e.*, for 44 months without losing their viability under lower moisture content in cold room at $+5^0$c. This showed that *O. abyssinica* seeds have Orthodox seed storage behaviour. However, a study on germination percentage of *Bridelia micrantha* species indicated that the seeds could not be stored for two months without decreasing in germination percentage (Eshete and Worku, 2011).

Effect of germination site on germination pattern of O. abyssinica seeds

Seeds started germination about 1-2 weeks after sowing and continued until the experiment was completed in 28 days. Out of the total 28 days of germination period (4 weeks), the 1st and 2nd weeks had best germination rates or potential germination periods for seeds germinated at laboratory (Figure. 2). The daily germination speed or the mean daily germination percent (Cumulative germination percentage divide by number of days since sowing) varied in different days in different storage periods for *O. abyssinica* seeds. The highest mean daily germination percentage was observed 7 days after sowing for seeds stored in 40 months; 8 days in 16 months; 7 days in freshly collected seeds and 7 days in 44 months of storage. Seed germination started at the 4^{th} day after seed sowing and continued up to the 14^{th} day at laboratory. On the other hand, germination delayed for the two sites, where best germination rate were observed in the 2^{nd} and 3^{rd} weeks at green house and seedbed (Figure. 3 and 4). However, the statistical test of ANOVA revealed that there was no statistical significant difference (F=0.003, 0.052 and 0.429, P<0.05) between the rate of germination of seeds and germinating sites (at laboratory, green house and seedbed), respectively.

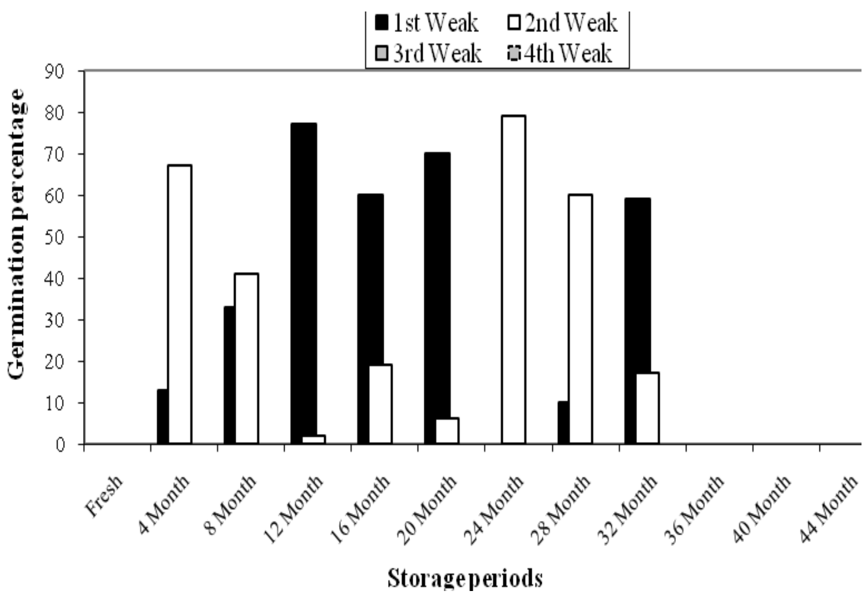

Figure 2. Germination pattern of *O. abyssinica* seeds at laboratory.

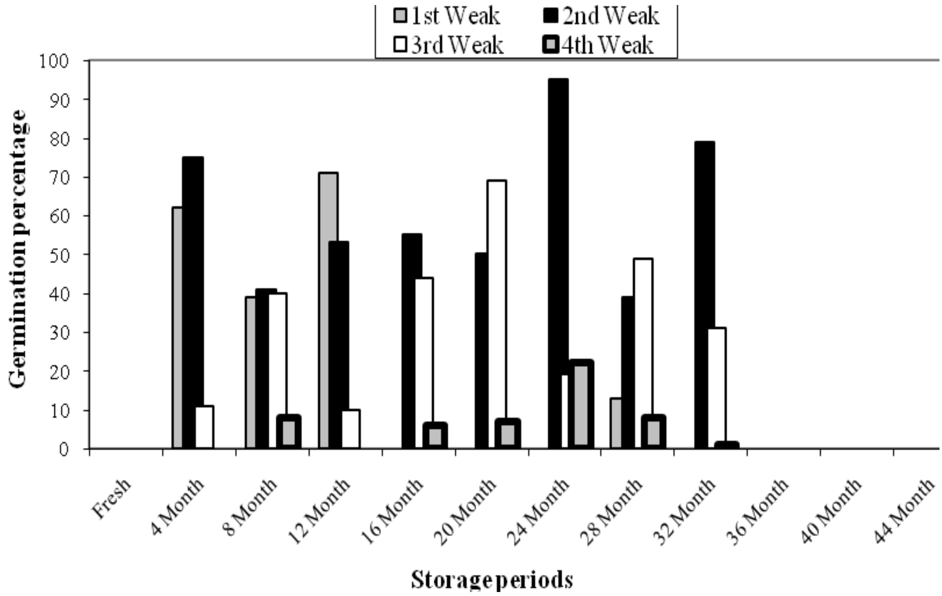

Figure 3. Germination pattern of *O. abyssinica* seeds at green house.

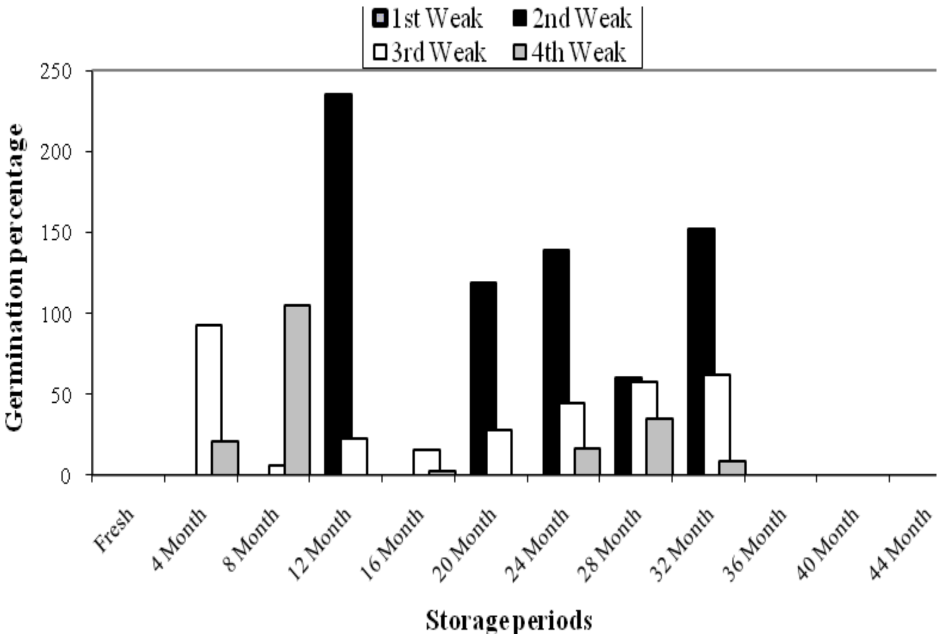

Figure. 4. Germination pattern of *O. abyssinica* seeds at seedbed.

Effect of germination site on germination energy and germination value of O. abyssinica seeds

The three various germinating sites, i.e., laboratory, greenhouse, and seedbed showed 70-83%, 25-69% and 0-59% germination energy respectively (Figure. 5, 6 and7). As a result, the germination energy of *O. abyssinica* seeds at three major germination sites indicated that laboratory recorded the highest germination energy of 83%, while the lowest percentage of 0% was observed at seedbed. Nevertheless, the statistical test of ANOVA showed that no significant difference (F=0.794, 0.222 and 0.843, P<0.05) was observed between germination energy of seeds and germinating sites (at laboratory, green house and seedbed), respectively.

From three various sites, laboratory showed best germination energy as well as carried out more or less under controlled conditions. Accordingly, out of the total 100 sowed seeds in 4 months of intervals at laboratory, all the germinated seeds recorded within the energy period of 14 days. No germinated seeds were recorded all in all after 14 days of sowing (Figure. 2). The highest germination energy was found from seeds stored for 40 months (83%) and the lowest in 28 months of storage (70%). On the contrary, seed germination was continued until the completion of the experiment in 28 days at green house and seedbed (Figure. 3 and 4). Germination energy is a measure of the speed of germination and hence the vigour of the seed and the seedlings it produces. Seeds which germinate rapidly and vigorously under favourable conditions of the laboratory are likely to be capable of producing vigorous seedlings, whereas weak or delayed germination is often fatal (Aldhous (1972) cited in FAO (1985)). Therefore, seeds with shorter germination period have greater germination energy (FAO, 1985). Similarly, the current results on *O. abyssinica* seeds reported that the seeds had greater germination energy (70%) as seeds germinated within a specified energy period, *i.e*., 14 days.

On the other hand, 1.30-6.16, 0.46-2.37 and 0.01-4.05 germination values of *O. abyssinica* seeds were recorded at the three various germinating sites (*i.e*., laboratory, green house and seedbed) respectively (Figure. 5, 6 and7). However, the difference was not statistically significant ($\chi 2$ =0.233, 0.243 and 0.230, P<0.05) between germination value of seeds and germinating sites (at laboratory, green house and seedbed), respectively. At laboratory, the germination value varied from 1.30 to 6.16 among the storage periods. The highest germination value was recorded in freshly collected seeds (6.16) and the lowest was under 4 months of storage (1.30). The highest germination value (6.16) observed in freshly collected seeds are an indication of the high vigour of *O. abyssinica* seeds. But the low germination values observed in the other storage periods may not necessarily mean due to low variability of seeds (Asiedu *et al*., 2011). Overall, as the graphs (Figure. 5-7) showed that germination energy more or less had a direct relationship with the germination value of *O. abyssinica* seeds at all sites.

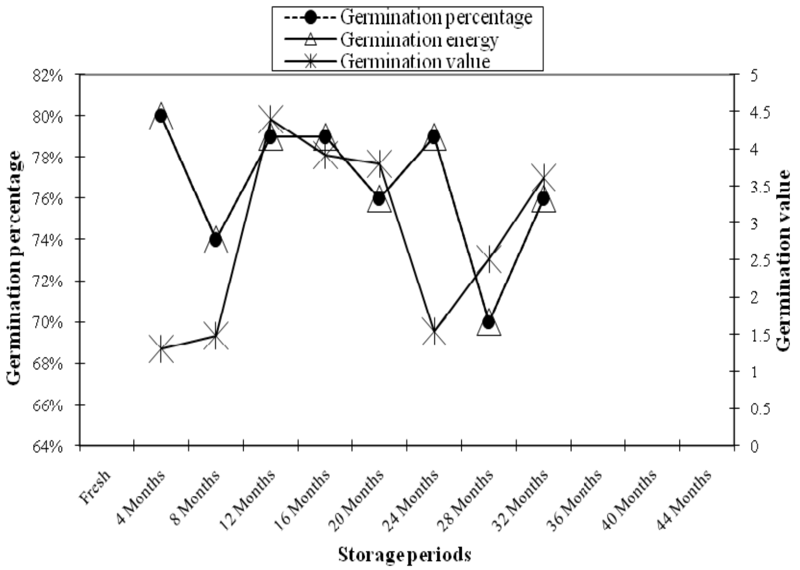

Figure 5. Germination percentage, germination energy and germination value of *O. abyssinica* seeds under different storage periods at laboratory.

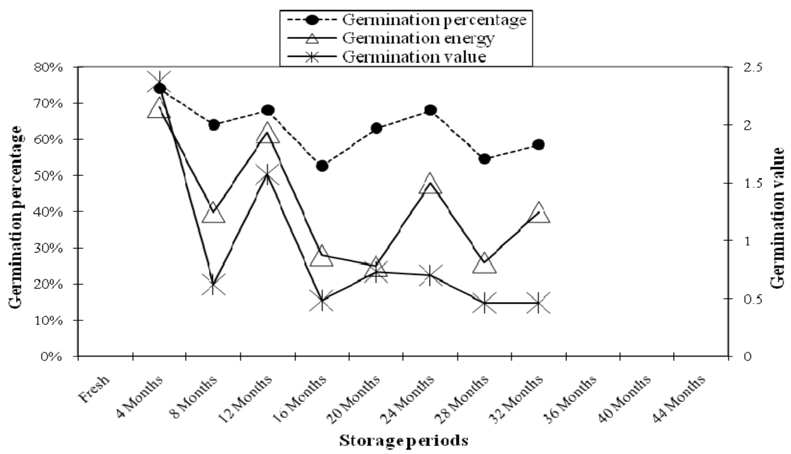

Figure 6. Germination percentage, germination energy, and germination value of *O. abyssinica* seeds under different storage periods at green house

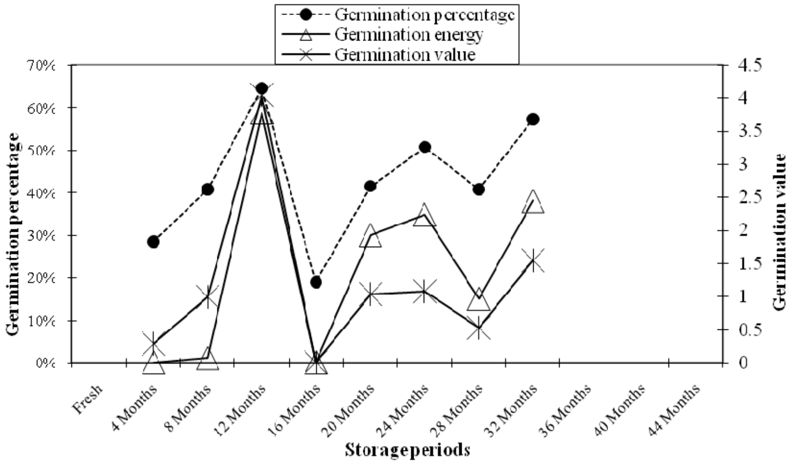

Figure 7. Germination percentage, germination energy, and germination value of *O. abyssinica* seeds under different storage periods at seedbed.

Conclusions and Recommendations

The current research results indicated that there were 8,393 seeds of the lowland bamboo (*O. abyssinica*) are contained within one kg of 78% pure seed. The bamboo seeds had the highest germination percentage of 83% within a range of 4-7% moisture content. Seeds started germinating about 1-2 weeks after sowing and continued until the experiment was completed in 28 days. Out of the total 28 days of germination period (4 weeks), the 1st and 2nd weeks had best germination rates or potential germination periods for seeds germinated at laboratory. There was a wider range of variation in germination percentage observed between germinating sites (at laboratory, green house and seedbed) might be due to differences in environmental factors including temperature and moisture variation. The mean daily germination percent varied in different days in different storage periods for *O. abyssinica* seeds. In addition, the seeds had high germination value (6.16) and more germination energy (83%); hence, germinate rapidly and vigorously. This enables easier production of vigorous and adaptable seedlings from seeds for large-scale plantation of the lowland bamboo.

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Natual Gum and Resin

Modelling to uncovering the future of frankincense production from Boswellia papyrifera in Ethiopia

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Introduction

Dry tropical forests including woodlands cover over 40% of the global tropical forest areas (Mayaux et al., 2005). In Africa alone, these forests cover 17.3 million km^2, and are home for half a billion people (Chidumayo and Gumbo, 2010). About 28 African countries host such vegetation types and in some of the countries, they are the only forest resources. Dry forests in Africa are profoundly important to enhance local livelihoods through support to livestock farming, providing essential services to rain fed crop agriculture, and generating cash and subsistent incomes from gathering timber and non-timber forest products (Chidumayo and Gumbo, 2010; Mulugeta Lemenih and Habtemariam Kassa, 2011).

Although less diverse than the wet forests in species composition, tropical dry forests also host considerable biological diversity of immense local, regional and international significances (White, 1983; Murphy and Lugo, 1986). An important feature of the dry forests in East Africa in particular is their richness in plant species of the genera *Acacia, Boswellia,* and *Commiphora* (Vollesen, 1989; FAO, 1995; Mulugeta Lemenih, 2005; Chikamai *et al*. 2008). Several of the species in these genera are renowned for being the sources of commercial gums and gum resins such as gum arabic, frankincense and myrrh; important export forest products for several countries in the Horn of Africa including

Ethiopia, Sudan, Eritrea, Somalia and Kenya (FAO, 1995; Chikamai, 2002; Chikamai and Cascade, 2005).

In Ethiopia alone, dry forests and woodlands in the semi-arid and arid agroecology covers nearly 55 Million ha (WBISPP, 2004). The vast *Combretum - Terminallia* broadleaved deciduous woodlands in the western and northwestern lowlands of the country are the home for *Boswellia papyrifera.* Frankincense from this species has been produced and traded since antiquity (Butzer, 1981; Bard et al., 2000), and still today it is product of local and national economic significance in Ethiopia and Eretria (Lemenih 2005; Ogbagzih, 2005). At the local level, its production is mostly farmer-based industry providing income to households. Thus, it serves an important function in terms of food security and income generation (Lemenih and Kassa, 2011). At national level, it is one of the articles for export for foreign currency earnings (Lemenih 2005; Lemenih and Kassa, 2011). During the past four decades engagement of both state owned and private companies have enhanced the production and marketing of gums and reins, resulting in significant increase in the production volumes and foreign earnings for the country (Lemenih, 2005; Lemenih and Kassa, 2011).

Yet, dry forests and woodlands in Africa in general and those in Ethiopia in particular are rapidly declining and degrading (Chidumayo and Gumbo, 2010; Bongers and Tennigkeit, 2011; Lemenih and Kassa, 2011). With these changes, biodiversity of the forests and woodlands and their ecosystem services are severely threatened (Chidumayo and Gumbo, 2010; Mulugeta Lemenih and Habtemariam Kassa, 2011; Abeje Eshete et al., 2011). For instance, in Ethiopia assessment of the status of the resource base shows a worrying trend (Akililu Negussie et al., 2008; Abrham Abiyu et al., 2010; Abeje Eshete et al., 2011; Mulugeta Lemenih *et al.*, 2011a, b). Most of the *Boswellia* stands are characterized by a lack of recruitment (complete hindrance of recruitment) through natural regeneration and very high adult mortality, hence a declining population (Abrham Abiyu et al., 2010; Abeje Eshete et al., 2011). The *Boswellia* woodlands are also heavily encroached by rapid land cover change to other land uses mainly cropland (Mulugeta Lemenih et al., 2011 a, b). No plan to manage forest is in place in major producing areas, tapping is uncontrolled, and enrichment planting is uncommon. Furthermore, there are no formal protective or control measures against fire and grazing (Mulugeta Lemenih and Habtemariam Kassa, 2011).

Promoting sustainable frankincense production requires the balance between economic and ecological uses of the woodlands and comparative analysis of the short-term rural development demand from alterative land uses on the one hand and the long term ecological and economic benefits from the woodlands on the other (Tatek Dejene *et al*., 2013). Some studies show that managing *Boswellia* woodlands for frankincense and other non-timber forest products, can offer competitive financial return with alternative agricultural land uses (Mesfin Tilahun et al., 2007; Tatek Dejene *et al*., 2013). Yet the woodlands are considered as having low economic potential, one of the factor leading to their wide spread conversion and use for settlement (Mulugeta Lemenih et al., 2011 a, b). Given all the challenges that the woodlands and the frankincense trees are facing, there is serious doubt of long-term prospect for a sustained supply of frankincense and other ecosystem services from the woodlands and the species.

One way to explore and predict potential future threats facing frankincense production is by means of modelling. Modelling coupled with scenario building to simulate various courses of action may significantly enhance the understanding of the potential impacts of the various threats that the woodlands and the frankincense (*B. papyrifera)* species are facing. Modelling could also play an important role by facilitating identification of management strategies that are likely to achieve a desired result. The objective of this paper was to employ scenario-modelling technique, simulate, and examine the future population of *B. papyrifera* and production of frankincense under various plausible assumptions and conditions that affect management and conservation of the frankincense bearing woodlands.

Materials and Methods

Study sites

The study was conducted in two woodland areas dominated by *B. papyrifera* trees: Abergelle in the north and Metema in the northwest. Both woodlands are known for having a high frankincense production and a long history of marketing of the product. However, there are several differences between the two sites in biophysical, socio-economic and livelihood conditions (Table 1). Abergelle is both one of the oldest and the main gum/resin production areas in Ethiopia. The production of this resource forms an important means for cash earning by local communities. This cash earning supplements subsistence-oriented mixed farming practices, namely smallholder crop cultivation (mostly sorghum, tef, and maize) and livestock keeping (Mulugeta Lemenih *et al*., 2011a). Metema was sparsely inhabited traditionally by people that practice shifting cultivation supplemented by hunting and gathering (Mekonnen, 2004). However, in recent decades, high population migration from highland to lowland is intensifying mixed crop-livestock production system that is negatively affecting the woodlands (Mulugeta Lemenih et al., 2007, 2011a, b). Migration to Metema from the highlands has intensified since the late–1960s/early–1970s, and it has changed significantly the demographic and ethnic composition of the district (Mulugeta Lemenih *et al*., 2007). The range use of the woodlands in Metema is also increasing. The woodlands are extensively used as rangelands by re-settled local people for grazing and by seasonally migrating cattle herders from the surrounding highlands (transhumance). According to a study by Azage Tegegne and colleagues (2009), 60.3% of the total cattle population in three nearby highland districts (Chilga, Dembia and Gondar Zuria) trekked to Metema for 6 to 8 months each year while the highlands were used for cultivating food crops. Unlike in Abergelle, the climate and the soil conditions in Metema are also suitable for the intensive cultivation of various crops, such as cotton, sesame, sorghum, finger millet, maize and tef, and the area has recently been opened up for the cultivation of most of these cash crops.

Table 1. Major biophysical and socio-economic land-use conditions in the three regions

Site attribute	**Abergelle**	**Metema**
Location		12_39′ and 12_45′N, and 36_17′ and 36 48′E
Area and population	3000 km^2 with the population of 113,526 inhabitants;	3995 km^2 with population of 83,193 inhabitants;
Climate conditions	Semi-arid;uni-modal rainfall and very erratic with mean annual rainfall of ca. 800 mm. Mean annual temperature of 22 °C;	Semi-arid to sub-humid; rainfall is uni-modal with Mean Annual Rainfall of ca. 965 mm; Mean Temperature 28 °C;
Altitude	Range between 1400-1650 m a.s.l.	Range between 549–600 m a.s.l.
Ethnic composition	Homogenous, Tigre ethnic group	Heterogeneous, with Amhara (80%), Tigre (10%), Oromo (5%) and Gumuz (2%). Increasing importance of immigrants
Main livelihoods	Mixed subsistence farming. Prevalent food insecurity stimulates alternative income earning	Mixed subsistence farming. Quick expansion of commercial farming of oilseed and cotton.
Original natural vegetation	*Combretum-Terminalia* woodlands and wooded grasslands. *B. papyrifera* and some acacia spp. predominate; Woodlands cover only small portion of the district	*Combretum-Terminalia* woodlands and wooded grassland. More diverse and higher in stature than in Abergelle. *B. papyrifera* is the main species. Woodland cover large part of the district
History of gum-resin production	the oldest commercial production region since 1940's. Systematic resin production through tapping	Systematic commercial production started recently (1980's), and has gradually intensified

	mainly in concession areas allotted to commercial firms	

Approaches and methods of data collection

The status of *B. papyrifera* population and its frankincense yield at a particular time and place is invariably affected by several factors, and is the balance between what is being lost (e.g. from deforestation and degradation) on the one hand and being recruited (e.g. through reforestation/afforestation and recruitment from natural regeneration) on the other (Figure. 1). This relationship requires diverse data collection using different techniques followed by model building. Components of the model were mainly two: (i) is the recruitment section, which comprises gain of new *B. papyrifera* trees through natural regeneration and from planting; reforestation/afforestation and enrichment planting (the left side of the model in Figure 1). And (ii) the mortality section, which comprises death and thus reduction of population from adult death (including degradation) and deforestation of the woodlands due to conversion into other forms of land use (Figure. 1). The third section of the model deals with incense yield per year, which is a function of *B. papyrifera* population and yield / tree/year (Figure. 1).

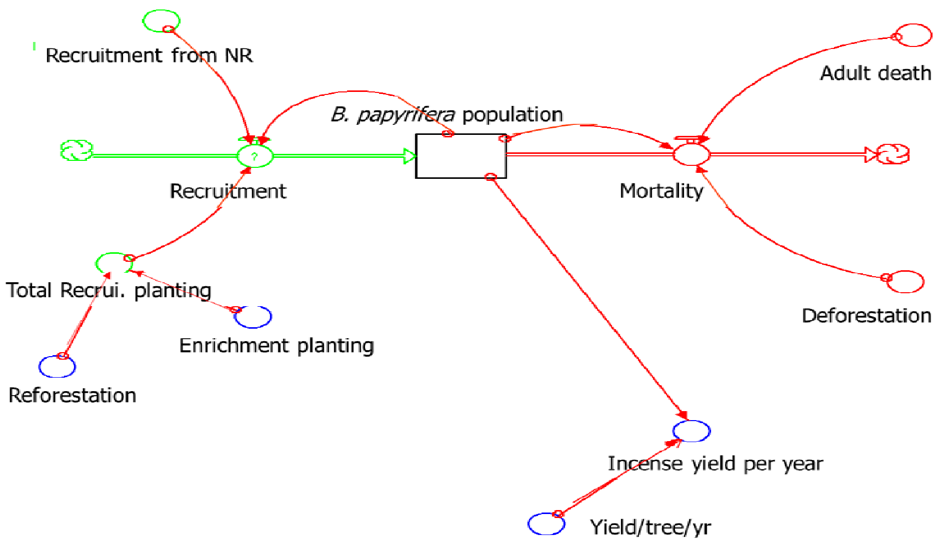


Figure 1. Model components for the quantitative projection of *B. papyrifera* population and its gum-resin production in northern Ethiopia

The data needed to run the model were obtained from an integrated research project called Frankincense, Myrrh, and Gum Arabic: sustainable use of dry woodland resources in Ethiopia (FRAME). FRAME employed a crossdisciplinary scientific approach ranging from landscape level geo-information studies to village-level socio-economic studies, plot level ecological and harvesting technology studies to tree-level eco-physiological studies. Based on FRAME studies a number of threats to the frankincense resources of the two regions were identified (Table 2).

Table 2. Major threats to *B. papyrifera* and frankincense yield in the two study districts.

Threats	Region	
	Metema	Abergelle
Competing land use pressure (Deforestation and conversion)	Very high	Low
Current management (reforestation and afforestation)	Non-existent	Non-existent
Protection of the standing stock	Very poor	Moderate
Production intensity	High and no control or regulating mechanism	High and no control or regulating mechanism
Adult mortality	Exceptionally high	Exceptionally high
Recruitment problems	Completely absent	Completely absent
Fire and grazing intensity	High	Low

Stand density, recruitment, mortality and yield studies

In Metema, 12 plots with the range of area 1.6-2.0 ha were established. In these plots complete census of population took place in 2007, 2008 and 2009 with the first census result of a total of 4370 trees with > 1 cm DBH and 2228 smaller individuals (seedlings and saplings). Identity of all species within the plot were recorded and the stem density of *B. papyrifera* per ha also determined. In the subsequent years (2008 and 2009), survival was assessed for all individuals. A similar study was carried out in Abergelle but only with two plots of 1.2 ha size. At both sites, tapping experiment to assess frankincense production per tree and year was also conducted. In both places, 25 trees of different diameter categories were marked and tapped with different intensities (3, 6, 9, 12, and 16 incisions per tree) during 2008 and 2009 tapping seasons. Incense tears produced during each cycle of collection were gathered, weighted and annual yield was obtained by averaging across diameter classes and tapping intensities to provide estimate of average production per tree/year. For details of this method, refer to Abeje Eshete (2011).

Deforestation study in the woodlands

Rate of deforestation of the woodlands, hence loss of *B. papyrifera* population was determined using multi-temporal remote sensing image from 1970 and 2010. Landsat TM images of bands 4, 3, and 2 were used for the 1970, while SPOT images of band 3, 2, and 1 acquired in 2007 were used to classify the land cover/use types of the area in 2007. ERDAS Imagine 9.1 software is used to process the satellite images and interpret the land use/cover of the study area over the 3 decades. Supervised classification method is used in ERDAS imagine in order to extract the Land use/cover of the study area. First scenes covering the area are identified and important bands are collected. Then, triple images of bands 4, 3, 2 in Landsat and 3, 2, 1 in SPOT are stacked to one image as layers. After identifying Images that cover the entire Metema and Abergelle districts, they were mosaiced and clipped to the district boundaries. Pseudocolor combination (bands 4, 3, and 2 as Red, Green, and Blue layers in Landsat and 3-2-1 in SPOT images), which is better for identifying vegetation, is selected for the land use/cover classification.

In the supervised classification, training areas (areas of interest) that represent separate land use/cover types are entered as signatures to the software. Then, the supervised classification is run for each site in iterative approach until land use/cover classification that is proximal to the reality is obtained. After the classification is completed, the classified raster files are converted to vector files in ArcGIS. Then, the area of each land use/cover class existing in each site is calculated. Finally, using the attribute tables of each land use/cover data of different years, the comparison, and analysis of the change in woodland area was performed. For verification purpose, GPS point data were taken and visual comparison was made with the classified images to determine the level of agreement (classification accuracy) with the existing reality of the ground.

Stakeholder engagement and definition of alternate scenarios

The two sites vary in terms of institutional and local efforts to restore the woodlands and stop degradation. Although in both sites land-use is dominated by farming using agro-silvopastoral practices. In Abergelle, the integrated land-use system that involve crop, livestock and forest production still prevails, but in Metema cash crop cultivation such as sesame and cotton is gaining prominence and is expanding rapidly at the expense of the woodlands due to its conducive biophysical conditions. Due to its biophysical suitability and large woodland size, not yet converted, human pressure on the woodlands in Metema is very intense and growing. Competition for land in the district stimulated informal institutional arrangements for land grabbing (Teshale Woldeamanuel, 2011). Consequently, in Metema, there is high rate of woodland degradation, while in Abergelle currently woodland conversion is minimal due to the strict formal control.

Given such differences, defining the various components of the model requires engaging local stakeholders to identify plausible alternative scenarios of reforestation/reforestation on the one hand and reduction of degradation on the other. Interviews (key informant and focus group discussions) followed by local workshops were employed for this. In Metema five key informants and four group discussions were held, while in Abergelle 20 household heads were interviewed. In Metema 34 individuals participated in a local workshop while in Abergelle 36 participants involved.

The outputs of the interviews and data from the field studies where combined with together on the participatory scenario workshop to define three alterative scenarios: business as usual (BAU), high intervention scenario (HIS) and low intervention scenario (LIS). A fourth scenario, called stabilizing scenario (SS) was lastly added by the researchers to indicate conditions that will maintain current population, which can be considered by policy makers as the minimum effort needed to stabilize the population at current state. The period considered was three decades with the reference year being 2010. The SS scenario presupposes interventions that address all the current adult mortality and deforestation through combinations of enrichment planting and reforestation with equal annual rate. The reference scenario, the BAU, will serve to reflect what will happen to the resource if there is no intervention and current disturbances continue for three decades to come. The two other alternative scenarios, HIS and LIS, represent the 'best and least' interventions that local stakeholders perceived as practicable for interventions on these woodlands given the political and socio-economic conditions of their respective districts. These interventions include actions to reduce deforestation, reforestation of deforested areas and replacement of adult death through enrichment planting.

Data analysis

The data representing each of the scenarios was fed into the model that was created with STELLA software trail version (Figure.1), and the future of *B. papyrifera* stem population in the woodlands and subsequent volume of frankincense production was projected accordingly. The relationship between the different inputs and outputs as built in the STELLA are presented in equations 1-5 as follows:

1) *B. papyrifera*_population(t) = *B. papyrifera*_population(t - dt) + (Recruitment - Mortality) * dt (1)

2) INFLOWS:

o Recruitment = { Place right hand side of equation here... } (2)

3) OUTFLOWS: (3)

- Mortality = (*B. papyrifera*_population*Adult_death)+Deforestation
- Adult_death = 0.07
- Deforestation = 0.00576 (30 ha/yr*192 stems/ha)/10^6

4) Recruitment_from_planting = Enrichment_planting+Reforestation.(4)

- Enrichment_planting = 0
- Recruitment_from_regeneration = 0
- Reforestation = 0

5) Incense_yield_per_year = *B.papyrifera*_population*Yield_per_tree_and_year

- Yield_per_tree_and_year = 0.0004..(5).

Results

Deforestation and forest degradation

Abergelle is one of the oldest and one of the main gum/resin production areas in Ethiopia. The production of this resource forms an important means for cash earning by local communities, hence an important component of the land use system. This cash earning supplements the mainly subsistence oriented mixed farming practices, namely smallholder crop cultivation (mostly sorghum, tef and maize) and livestock keeping. The woodlands are formally public resources, but communally used. They are equally valued for frankincense production and for livestock rangeland use. Crop cultivation is also prevalent. Long years of human habitation and the intensive extraction of wood and frankincense have significantly shrunk the woodlands.

However, since recent years institutional environment for forest protection has significantly improved such that deforestation has completely to fade. Furthermore, various initiatives to enrich the frankincense resource have been started by both individual farmers and the state. The efforts by individual farmers involve the preservation of naturally regenerated trees as on-farm private trees (parkland agroforestry). State-supported efforts involve restoring degraded areas with exclosure establishment, reforestation, and improving frankincense production system by introducing resting period in the production cycles. However, there have been two serious problems beyond the controls of locals as well as concerned government agencies: complete absence of recruitment from natural regeneration and high level of adult mortality. These problems are, in fact, not new to Metema, but have been reported from several *Boswellia* dominated woodlands.

The situation in Metema is a bit different. This area was inhabited by the Gumuz people who mainly live on hunting and gathering supplemented by sporadic shifting cultivation. Over years, however, immigration of highlands introduced new forms of land use: mixed crop plus livestock production system. Livestock production is an 'open access' type: they are used by re-settled local people for grazing and by seasonally migrating cattle herders from the surrounding highlands (transhumance).

Migration to Metema from the highlands has intensified since the late 1960s/early 1970s. And following immigration croplands have also expanded considerably at the expense of the woodlands. The woodlands are openly accessed by a traditional system of land claim called 'Mate Qedem' and 'Mofer Zemet'. Mate Qedem means 'marked first.' Once a woodland area has been marked, the user-right of whoever marked it will not be disputed by others. Mofer Zemet means 'campaign with plough'. It is a system whereby highlanders who do not permanently dwell in the district come down in the summer and clear and cultivates as much land as they can, and then harvest their crops and leave the area.

Because of the intensifying clearance for crop cultivation in the district, pasture woodlands are rapidly declining. The average deforestation rate in Metema for the past four decades (1970s - 2010s) was 1850 ha/year in contrast to almost zero in Abergelle. Deforestation was near zero in Abergelle due to stringent local institutions that control forest clearance and conversion, while this was extremely soft in the case of Metema. However, woodlands in both districts are facing severe degradation from high level of adult mortality (7%) and lack of recruitment through natural regeneration (0%).

Definitions of inputs to the scenarios and predictions of population and frankincense yield in Metema

Input data obtained from field studies and participatory scenario workshops for Metema where summarized in Table 3. From the participatory scenario workshop, deforestation was assumed able to reduce by 30% and 70% in the LIS and HIS, respectively. On the other hand, afforestation/reforestation rate was estimated to be equal to 50 ha/year and 100ha/ year for the LIS and HIS, respectively. In addition, in the case of HIS case enrichment planting that can replace 2.1% of the 7% adult mortality, which was equal to 4 trees/ha/ year was assumed a possibility (Table 3). The SS assumes replacement of the deforestation rate through afforestation and at the 1600 trees/ha planting rate and 50% survival the equivalent area that should be annual afforested is 444 ha (Table 3). It was also assumed that a planted seedling needs about 10 years to produce incense and thus 10 years time lag was considered for stem gains through reforestation and afforestation to offer frankincense.

Table 3. Alternative scenarios and their attributes in Metema for projection of stand population and frankincense production over the coming 30 years

Parameters and scenarios	Value	Remarks
Current status		
• Average Boswellia stem density (stem/ha)	192	Data from field assessment
• Total area of woodlands in the district (ha)	270,000	Data obtained from District office of Agriculture
• Initial total Boswellia population	51,840,000	Woodland area * mean stem density/ha
• Current recruitment (No. stems/ year /ha)	0	No recruitment through regeneration
• Frankincense yield (kg/ha/ year)	76.8	Based on 0.4 kg/tree/yr yield
• Initial frankincense yield in the district in tons/ year	20736	Yield/ha/yr*woodland area
• Adult mortality (%)	7	Per cent of standing stock (ca. 13.5 stem/ha/ year)
• Annual deforestation rate (ha/ year)	1855	Equivalent of 0.49% of the woodland area
BAU Scenario		
• Adult mortality rate (%)	7	13.5 stems/ha/ year
• Annual deforestation rate (ha/ year)	1855	
• Natural recruitment No. of stem/ha/ year)	0	
• Reforestation/afforestation (ha/ year)	0	
• Enrichment planting Low Case scenario		
• Adult mortality rate (%)	7	
• Annual deforestation (ha/ year)	925	Reducing deforestation by half
• Natural recruitment (No. of stem/ha/ year)	0	
• Annual reforestation/afforestation (ha/ year)	50	At 1600 seedlings/ha planting rate
• Seedling survival rate (% of total planted)	50	Based on assumption by stakeholders
• Enrichment planting (stem/ha)	0	
High case scenario		
• Adult mortality rate (%)	7	
• Annual deforestation (ha/ year)	555	Reducing deforestation by 70% of current rate
• Natural recruitment (No. of stem/ha/ year)	0	
• Reforestation/afforestation (ha/ year)	100	At 1600 seedlings/ha planting rate
• Seedling survival rate (% of total planted)	50	Based on assumption by stakeholders
• Enrichment planting (stem/ha)	4	Replacing 30% of current adult mortality (ca. 4 stem/ha/ year)

Stabilizing scenario		
• Mortality rate (%/year)	7	
• Deforestation (ha/yr) (70% reduction)	1850	
• Natural recruitment (No. of stem/ha/ year)	0	
• Reforestation plantation (ha/ year)	444*	≈1850 ha/ year deforestation at 1600 stem planting with 50% survival
• Planted seedling survival rate (% of total planted)	50	
• Enrichment planting (stem/ha)	13.4	100% of adult mortality

**because of 1600 stems/ha in plantation the planted area is lower than the deforested area. Enrichment planting also reduces the area needed for planting.*

The projection for *B. papyrifera* stem population and the subsequent volume of frankincense expected under the four scenarios for Metema showed a continuous and alarmingly decline for both (Figure 2). After 30 years only 3% of the current stem density of *B. papyrifera* will be expected to remain under the BAU scenario, while 8% and 20% will be expected under LIS and HIS respectively (Figure 4). The fact that expected stem density and frankincense yield are declining rapidly with widening gap under all the scenarios with respect to the SS implies that much more efforts are needed than those already considered as '*possible interventions*' by the stakeholders to conserve the resources and sustain incense production. Whether such efforts are plausible or not is yet to be seen.

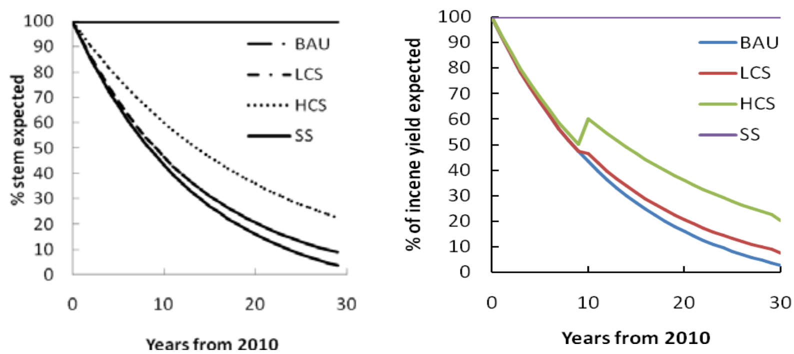


Figure 2. Expected per cent of B. papyrifera stem (left) and frnakincene yield (right) under the four alternative scenarios over the coming four decades (BAU = Business as usual; LCS = Low case scenario; HCS = high case scenario; SS = stabilizing scenario).

Definition of inputs into the scenarios and prediction of future population and frankincense yield for Abergelle

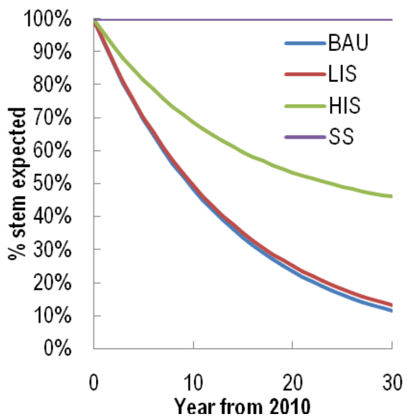
In Abergelle during the last two decades there has been no significant deforestation due to improved forest protection, hence deforestation is assumed zero. However, degradation which is mainly due to adult mortality is prominent taking place at the rate as high as 7% same as that of Metema. Furthermore, similar to the case in Metema there is general lack of recruitment through natural regeneration. Including the information generated from the participatory scenario workshop data used in the model prediction for the Abergelle are summarized as shown in table 4 below. In the case of Abergelle, stakeholders are better optimistic with respect to reforestation and assumed that 75 ha/year and 150 ha/year planting are possible under the LIS and HIS respectively.

Table 4. Alternative scenarios and their attributes in Abergelle for projection of stand population and frankincense production over the coming 30 years

Parameters	Value	Remark
Average *B. papyrifera* stem density (stem/ha)	281	
Total area of woodlands in the district (ha)	150000	
Initial (year 0) total *B. papyrifera* population (Area * mean density)	42150000	
Frankincense yield (kg/ha/ year)	0.4	
Current recruitment (No. stems/ year /ha)	0	
Adult mortality (%)	7	
Annual deforestation rate (ha/ year)	0	
Scenarios		
BAU		
Adult mortality rate (%)	7	
Annual deforestation (ha/ year)	0	
Natural recruitment (No. of stem/ha/ year)	0	
Reforestation/Afforestationn (ha/ year)	0	
Enrichment planting (% of adult tree mortality)	0	
Low Case scenario		
Adult mortality rate (%)	7	
Deforestation (ha/yr)	0	
Natural recruitment (No. of stem/ha/yr)	0	
Reforestation/afforestation (ha/yr)	75	At 1600 seedlings/ha planting rate
Planted seedling survival rate (% of total planted)	50	
Enrichment planting (stem/ha)	0	
High case scenario		
Mortality rate (%)	7	
Deforestation (ha/yr) (70% reduction)	0	
Natural recruitment (No. of stem/ha/yr)	0	
Reforestation plantation (ha/yr) (100 ha/yr)	150	At 1600 seedlings/ha planting rate
Planted seedling survival rate (% of total planted)	50	

Enrichment planting (stem/ha)	6.9	35% replacement of current adult death
Stabilizing scenario		
Mortality rate (%/yr)	7	
Deforestation (ha/yr) (70% reduction)	0	
Natural recruitment (No. of stem/ha/yr)	0	
Reforestation plantation (ha/yr) (100 ha/yr)	150	At 1600 seedlings/ha planting rate
Planted seedling survival rate (% of total planted)	50	
Enrichment planting (stem/ha)	18.9	100% replacement of adult death minus reforestation

The projection for Abergelle also showed that tree density and frankincense yields under all scenarios will continuously and rapidly decline (Figure. 3). After 30 years from now only 11%, 13.1%, and 46% tree density of *B. papyrifera* will be expected under BAU, LIS, and HIS, respectively (Figure 3). Similar trend of frankincense yield were predicted under the respective scenarios (Figure 3).



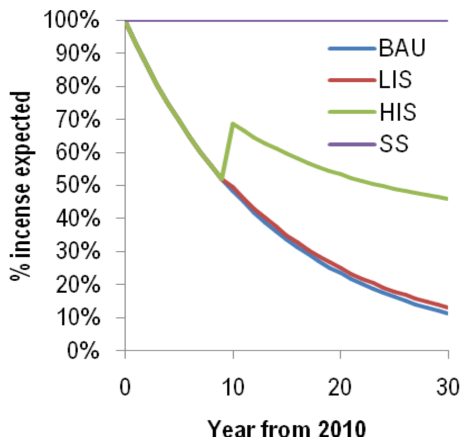


Figure 3. Expected *B. papyrifera* stem (left) and frankincense yield (right) in Abergelle over the coming three decades under the four alternative scenarios (BAU = Business as usual; LCS = Low case scenario; HCS = high case scenario and SS = stabilization scenario).

Discussion

The scenario modeling presented above prompt the rapid downward development of frankincense resources in Ethiopia. Both the tree density and frankincense yield of expected to rapidly decline over time. The major bottlenecks, as can be shown in the trends are the extra high adult mortality and a complete absence of recruitment from natural regeneration (Abeje Eshete, 2011). These two are in fact driven by other direct and underlying factors of degradation. The most direct is increasing fire frequency and livestock grazing (Mulugeta Lemenih et al., 2007; Abeje Eshete, 2011). The underlying drivers are probably population growth (Mulugeta Lemenih et al., 2007). Human and livestock population are increasing in these woodlands. These have in turn instigated new forms of woodland-people relationships in which fire incidences, livestock grazing, and intensification of incense tapping are observed. There is heavy unregulated and unmanaged livestock grazing and wood product harvest in most *Boswellia* woodlands. The high level of negative anthropogenic interferences in frankincense woodlands are severely threatening not only the rapid decline but likelihood of disappearance of the resource in just half a century from now if conditions of management will not change. This is alarming for a country with long history of frankincense production and trade as well as cultural attachment. Efforts so far both at local grassroots and country levels for improved management of the species and conservation of frankincense woodlands are limited. Domestication processes and efforts are very low. Most alarming is the fact that plausible management intervention alternatives as perceived by the local stakeholders do not seem to reverse the downward trend of frankincense resources. This might call for rather concerted large-scale effort from all concerned at much higher decision-making level than just local stakeholders might.

The population of *B. papyrifera* is experiencing missing classes in sapling stages in the regeneration profile (Abrham Abiyu *et al*., 2010; Abeje Eshete, 2011), while high adult mortality is a major constraint in the higher classes for population stability (Abeje Eshete, 2011). Survival rate of regenerating seedlings and adult trees in frankincense woodlands showed that both cases are lower than most commonly reported survival rates of juvenile and adult trees in dry tropical forests (Abeje Eshete, 2011). Yet, no relation between survival rates both for adult and young seedlings and soil and other biotic conditions common to the environment of the woodlands can be established (Abeje Eshete, 2011). Therefore, factors that constrain stability of population of the frankincense tree are those beyond the natural environment of soil and associated biotic effect.

Furthermore, seeds of the species show no problem of germination. Many factors, other than edaphic and biotic factors, potentially influence population growth and survival. Some of these could be anthropogenic disturbances and others environmental specifically climatic. Annual seedling emergence through natural regeneration is also good. Nonetheless, emerged seedlings could not cross into the higher stage, sapling stage, causing a complete absence of saplings from across most frankincense woodlands. Nursery raised and transplanted seedlings showed a similar problem. Because of this, most studies point to anthropogenic factors to have been affecting both the survival of seedlings and adults. These factors most revolve around human induced fire incidences and grazing pressure.

Nonetheless, these factors are also ‘assumed factors’ or ‘likely to be factors’ based on causal relationships as perceived by locals (Abeje Eshete, 2002; Mulugeta Lemenih *et al*., 2007; Tatek Dejene, 2008). In fact, over the last four to five decades human and livestock population have rapidly increased in the these woodlands, and so do fire incidences, livestock-woodland interactions and human harvest of forest products (Mulugeta Lemenih *et al*., 2007; Abeje Eshete, 2011; Mulugeta Lemenih *et al*., 2011a, b; Mulugeta Lemenih and Habtemariam Kassa, 2011). These have been remarked by local people as major cause for the problems observed in the woodlands (Mulugeta Lemenih *et al*., 2007; Abeje Eshete *et al*., 2011; Mulugeta Lemenih *et al*., 2011a; Mulugeta Lemenih and Habtemariam Kassa, 2011). The high rate of deforestation experienced in Metema (e.g. Emrie and Tarekegn, 2010) is a reflection of this reality. This intensive and unregulated human disturbances, no doubt are part of the responsible factors for the lack of saplings across the habitats through limiting the growth of seedlings to saplings.

Whether the problem is caused by these local anthropogenic factors or more by global phenomenon such as general effects of environmental changes such as climate processes is hard to specify. The correlation between local anthropogenic factors and problems of frankincense resource is simply because as human and livestock population grows in the frankincense woodlands, their vitality tended to degrade. To confirm such hypothetical and casual relationships, more rigorous and well-designed researches need to be conducted. Therefore, besides policy measures to manage human-woodland interactions, researches need to be strengthened on the interactive effects of soil conditions, climate, disturbances by grazing, fire, forest products harvesting including frankincense production through tapping. For the short term, strategic intervention is needed through conservation area delineation of large tracts of land in which human-livestock contacts will be as minimum as possible.

Conclusion

This study reveals that *B. papyrifera* and its frankincense products in Ethiopia are under severe threat. Most worrying is the fact that the interventions perceived as practicable by local stakeholders fall short to stabilize the situation. The conditions in the SS prompted that much more efforts than those conditions suggested by the stakeholders are needed to stabilize the tree population and sustain frankincense yield at current level and interventions suggested by SS are likely to be implemented or not is yet to be seen. Whatever the case, the situation tends to call upon urgent supports from wider communities than just the local stakeholders do and indeed engagement of local, national, and international communities might be necessary to sustain the production of this ancient and important socio-economic product, frankincense, and its resource base.

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Effect of Tapping Intensity and Tree Diameter on Gum Arabic Yield of *Acacia Senegal* (L) Wild in Southern Ethiopia

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Introduction

Gum arabic is a dried exudate obtained from the stem and branches of *Acacia senegal* trees (FAO, 1999). Gum arabic is a natural product with wide industrial uses; hence, it is a product traded on international market. Several African countries and local farmers in the resource area are benefiting immensely from its production and trade. Gum arabic is produced either from natural oozing or by stem wounding (a practice called tapping). Ethiopia is one of the producer countries in Ethiopia with huge potential for future sustainable production.

Most of the current gum arabic production in Ethiopia is from natural exudates (Mulugeta Lemenih. 2005). Collection is mostly carried out by cattle herders, women, and children from tree trunks and branches. Collections are not restricted to gums on trees but also fallen pieces are picked often from the ground, which deteriorate the gum quality (Adefires, 2006). Tapping for production of gum arabic involves removing sections of the bark with a sharp material (e.g. axe) (Girmay and Mulugeta, 2007).

Tapping is practiced to enhance yield and quality as well. For instance, tapping activities increased gum arabic yield by 77.42% when compared with untapped trees in Kenya (Wekesa *et al.*, 2009). However, in the production system in Ethiopia, there has been no culture of tapping the trees, which is mainly due to lack of knowledge about tapping. The aim of the present study was to investigate the effect of tapping intensity and tree diameter class on gum arabic yield and to develop optimum tapping intensity based on stem diameter class for *A. senegal*.

Materials and Methods

The study site

The study was conducted in Yabello district of the Borana lowlands in southern Ethiopia. The district covers an area of 5550 km^2 with the altitude range of 1350 - 1800 m (Coppock, 1994). The area is characterized by a bimodal rainfall pattern. The main rainy season with 60% of the annual precipitation is between March and May followed by a cool dry season between June and August. The short rainy season with 40% annual precipitation occurs from September to November, and this also followed by the long dry season that extends from December to February (Adugna and Aster, 2007). The mean monthly and annual rainfalls are 48 mm and 587.2 mm respectively. The mean monthly minimum and maximum temperatures of the district are 15.6 and 18.8 ^{0}C, respectively, with a mean annual temperature of 18.3 ^{0}C (Coppock, 1994).

The dominant vegetation types are *Acacia, Boswellia* and *Commiphora* (ABC) Genera and bush savanna, mixed with perennial grasses such as *Chrysopogon aucheri*, *Cinchrus ciliaris, Themeda triandra*, and *Sporobolus phyramidalis* (Ayana, 2007). The main soil types of the region are red sandy-loam soil, comprise 53% sand, 30% clay and volcanic light colored silty clay and 17% silt and Vertisols (Coppock, 1994).

Data collection and design

The study involved a factorial experiment where four levels of tapping intensity and three levels of tree size (diameter class), in total 12 treatment combinations, were combined, and arranged in a randomized complete block design (RCBD) form. Three blocks (replications) were used. The four tapping intensities tested were untapped (control), 4 stop tapping, 6 spot tapping and 8 spot tapping. For the tree size treatment, size classes of 3.0 – 6.0 cm, 6.1- 9.0 cm, 9.1 – 12.0 cm diameter classes were used. Trees in these diameter classes were referred to as small, intermediate, and large trees, respectively. Three stands of size 100 x 100 m composed of natural population of *A. senegal* trees were selected along a slope gradient to form the blocks. The blocks were separated by 100 m. Within each block, all *A. senegal* trees were counted and measured for DBH using caliper. They were classified according to the above diameter classes. From each block, 36 sample trees were selected randomly according to 12 treatment combinations; each treatment combination was applied on three *A. senegal* trees. A total of 108 (36*3) sample trees were involved in the study. The trees were marked properly with a label that represents the treatment combination name and replication number.

Tapping was made by a traditional axe by wounding the bark of the sample trees at the DBH (1.3 m) both on the east and west facing sides of the trunk. Equal number of spots having a length of 10 cm and width of 3 cm each were applied in eastern and western side of the trees (Howes, 2001; Wekesa *et al.,* 2009). Each consecutive spots were separated by 10 cm. Gums were collected in two picking rounds: the first picking was 30 days after tapping and the second picking was 20 days after the first picking. The collected gum was dried at room temperature for one week (Mohammed and Rohle, 2009) and weighed.

Data analysis

The data on gum yield was analyzed in a two-way ANOVA using statistical analysis system (SAS-Version 9). Mean separation for significantly different means was conducted by using Duncan's multiple range test (DMRT). The relationship between gum arabic yield, tapping intensity and tree diameter class was computed using Pearson's correlation coefficient and linear regression. Two sample-paired t-test was carried out to compare the first and second picking rounds.

Results and Discussion

Gum arabic yield differed significantly ($P < 0.05$) between the different tapping intensities during the two picking rounds (Table 1). Tapped trees generally provided significantly higher yield than untapped control trees. The gain in yield by tapping ranged from 628-704% during the first round picking and 848-958% during the second round picking over the untapped control. This finding conforms to similar studies in the Sudan where tapping yielded far more yield than untapped trees (Ballal *et al.,* 2005b).

Table 1. Gum arabic yield (g) between tapping intensity and tree diameter class in the first picking round (Mean ± SE)

Tapping intensity	Tree diameter class		
	D1	D2	D3
T1	1.33 ± 0.015^{aA}	0.85 ± 0.006^{bA}	0.00 ± 0.00^{cA}
T2	5.96 ± 0.020^{aB}	5.31 ± 0.018^{bB}	4.27 ± 0.028^{cB}
T3	6.32 ± 0.026^{aC}	5.58 ± 0.028^{bC}	4.51 ± 0.105^{cC}
T4	6.68 ± 0.014^{aD}	5.85 ± 0.062^{bD}	4.84 ± 0.031^{cD}

Means within a row that have a different small letter are significantly different from each other and means within a column that have a different capital letter are significantly different from each other ($p < 0.05$).

There was a significant positive correlation (r = 0.64, p = 0.0001) and (r = 0.68, p = 0.0001) between tapping intensity and gum arabic yield in the first and second picking rounds, respectively (Figure 1 middle and right). Hence, by increasing tapping spots per tree yield increases and this is in fact similar with results reported from other studies on *Boswellia papyrifera* for frankincense (Asmamaw and Abeje, 2007) and on *A. sengal* from Sudan (Ballal, 2005a). However, other studies (Fadl and Gebauer, 2004b) also reported irregular gum, yield increment due to tapping intensity from *A. seyal* tree.

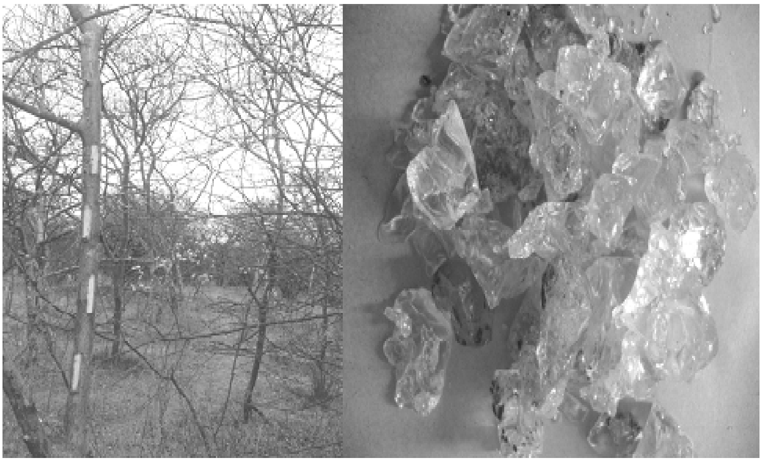

Figure 1. Tapped tree and the size of gum arabic tears that oozed from tapped spots (Photo: Semegnew T.)

On the contrary, tree size was negatively related to gum yield. During the two picking rounds, the highest yield was obtained from trees in the smallest diameter class (3.0-6.0 cm) than the other classes (Table 1). This result was also consistent with the works of Wekesa *et al.,* (2009) and that of Abdalla, (2005). This is believed to be related to root architecture and physiological activities of the trees that directly are reflected in the stress level of the trees. In smaller trees have fewer fine root numbers that intersects in the surface soil layer and also lower root density with increasing soil depth, hence reduced ability to tap water from large volume and depth of soil. This makes small sized trees to experience high water stress during dry seasons resulting them to produce more gums when tapped (Wekesa *et al*., 2009).

In terms of picking cycles, significant difference ($t = 2.59$, $P = 0.01$) was observed in gum arabic yield between first and second picking rounds. The first round yield was greater than the second round yield across all intensity and diameter class by the factor of about 12%. While mean yield across all tapping intensity and diameter class was 4.29 gm per tree for the second round picking this was 3.77 gm. Similarly, Wekesa *et al.,* (2009) reported gum arabic yield to decrease from first to second picking round. Moreover, Ballal *et al.,* (2005a) and Abdalla, (2005) stated that the first and second picking have an important factor in gum arabic production and could be used as an indicator for the prediction of total gum arabic yield. On the other hand, Ballal *et al.,* (2005b) pointed out that gum arabic production increase from first pick, reached its peak in the second pick, decreased slightly in the third pick, and then fell subsequently up to eight pick. This reduction of gum arabic yield from first to second picking rounds might be due to sealing of some part of the wounding spots after the first picking time that makes exudation going on only in small holes of the wounding spots.

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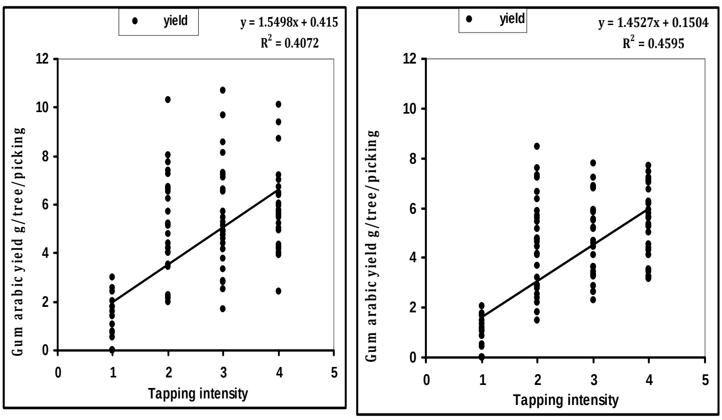

(a) (b)

Figure 3: Correlation between yield of gum arabic and tapping intensity in the first picking (a) and second picking round (b) (1 = control, 2= 4 tapping spot per tree, 3 = 6 tapping spot per tree 4 = 8 tapping spot per tree.

In terms of overall productivity per tree and year, various studies reported wide variations in yield per tree. For instance, Badi *et al.* (1989) reported the yield of 0.5–0.6 kg/tree/year; FAO (1995) 250 gm/tree/season; Ballal *et al.* (2005b) 10.8 gm/tree/season; Chemulanga *et al.* (2009) 0.66-0.81 gm/tree/season; Wekesa *et al.*, (2009) 5.15 gm/tree/season. The mean yield reported from this study for the two picking rounds, which is 10.35gm/tree/season (by excluding the control treatment) is more or less similar to yield reported by Ballal *et al.,* (2005b) and higher than that of Wekesa *et al.,* (2009) and Chemulanga *et al*., (2009) but lower than reported by Badi *et al*., (1989) and FAO (1995a). This difference in yield of gum arabic might be due to seasonal and site variations. During the experimentation time there was low temperature, which may create difficulty in producing higher amount of gum arabic yield. For example, with regard to temperature IIED and IES, (1989) reported that a high temperature at tapping time is conducive to high gum production while a low temperature seems to seal off the gum exudation points, resulting in low yield. Similarly, increase in yield associated with increase in the mean maximum daily temperature of the area and increased stress on the tree (Abeje, 2002; Kindeya, 2003).

Conclusions and Recommendations

The results of this study revealed that yield of gum arabic increases with increasing tapping intensity. Higher gum arabic yield was observed in tapping practice than untapped (natural collection). However, the reverse is true for diameter classes. The higher gum arabic yield was resulted in small diameter (3- 6 cm) than middle (6.1-9.0 cm) and large diameter class (9.1-12 cm). Within untapped treatment combination there was no yield at all in large diameter class in the first and second picking rounds. Several researches have confirmed that small diameter class trees produce more gum arabic than larger diameter trees. Therefore, for sustainable use of the species, commercial gum arabic tapping should be conducted at early stage and when *A.senegal* trees have more than 9 cm dbh, it can be used for other values, like fodder, firewood, charcoal etc. With regarding to number of picking rounds, the first gum picking round appears to be an important factor in gum arabic production and could be used as an indicator for the prediction of the total gum yield for *A.senegal.* Because first picking yielded more gum than the second picking round. Finally, based on this study, tapping intensity at 8 spots per tree could be used as optimum tapping practice for all tree diameter classes (3-6 cm 6.1-9 and 9.1-12 cm) for sustainable production of gum arabic. The following recommendations are also forwarded:

- This study was conducted from July to mid of September during the short dry season in the area. We expect that gum arabic yield would be much greater than reported had the experiment was done during the long dry season (December-March) which is the main gum Arabic production period in the area. We therefore suggest further research during this long dry season;

- The impact of tapping intensity on the tree health, physiology and reproduction should be investigated to balance yield with tree vitality; hence to insure sustainability, and
- To make advantage of the yield increment from tapping, training of the producers is essential as this practice is not known in the area yet.

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Vegetative Propagation of *Boswellia papyrifera* by Cutting: Plantation Time and Cutting Size Affect Survival

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Introduction

Boswellia papyrifera (Del) Hochst is multipurpose tree species better known as the source of frankincense. Its tree population is declining in all its growing geographical area in arid and semi-arid areas. Reports showed the major reasons for decline of its population are land clearing for agriculture, free range browsing, manmade fire, improper tapping for frankincense production, insect attack especially beetles (Gebrehiwot *et al*., 2003; Lemenih *et al*., 2007). Tree population structure of the species showed little or no representation of smaller individuals. The regeneration is also impeded with many kinds of limitations. For details of population structure, regeneration problems and restoration possibilities refer (Abiyu *et al*., 2010; Abeje *et al*., 2005) and the references there in. Recent report showed under protected conditions with exclosure and in the absence of resin tapping and free browsing, despite the occurrence of numerous seedlings, recruitment to the next cohort class was fully impeded due to seedling mortality, which approximates 100% (Negussie *et al*., 2008). Vegetative propagation by means of stem or branch cutting did give positive results (Negussie *et al*., 2009) for assisted restocking of incense woodlands.

Vegetative propagation methods are useful tool for timely production of quality propagules for reforestation, genetic conservation, or domestication programes. The usual practice involves, stem cuttings taken to the nursery where they will be subjected to grow roots in a media for sometime before plantation. The most common methods applied to foster root development from cuttings are

- treating the cuttings with synthetic plant growth regulators (Swamy *et al*., 2002; Tchoundjeu *et al*., 2002; Husen and Pal, 2007);
- inoculation of the rooting media with ectomycorrhizal fungi or rhizobacteria (Niemi *et al*., 2002; Teixeira *et al*., 2007);

- concentrates of marine algae (Crouch *et al*., 1992; Crouch and Vanstaden, 1993);
- extracts from other plants (Ljung *et al*., 2001; Ljung *et al*., 2005; Negussie *et al*., 2009) that are able to stimulate adventitious root formation.

However, the development of low-technology propagation methods that could easily be transferred for practitioners and local people is important (Leakey, 1990; Gautier, 1996).

Indigenous knowledge in the drier parts of Africa showed *Ficus thonningii* propagated vegetatively (Danthu *et al*., 2002). Particularly in northern Ethiopia *F. thonningii* is propagated vegetatively with little extra treatment. The local knowledge advises that either branch or stem cuttings can be used. The age of the parent stock is greater than 2 years, cuttings prepared in the months of March and April that means, three to four months before the beginning of the rainy season, the average length of the cutting usually about 3-4 meters, and diameter 10-30 cm and should not be planted immediately. The time lag between plantation and cutting material preparation is three to four weeks, what they refer it as curing time. The farmers' rationale behind this indigeneous knowledge is that rejuvenation is ensured and browse by small ruminants will not be possible as the plant will be above browsing height. Similarly, restoration experiments showed planting large vegetative stakes ~2-4 m tall develop a more extensive rooting system and were more resistant to drought than seedlings (Zahawi and Augspurger, 1999, Zahawi, 2008; Zahawi and Holl 2009 ;). Furthermore, in addition to the size of cutting material, season when the planting material was prepared and plantation took place (Danthu et al., 2002; Welander, 1994) and age of ortet and position on the parent stock (Greenwood, 1987; Opuni-Frimpong *et al*., 2008) reported to have affect of the root growth and survival of stem cuttings in vegetative propagation methods.

The objectives of this experiment was therefore, to study the effect of cutting size specifically butt end diameter and length of the cutting, and planting season on the survival of branch cuttings of *B. papyrifera* tree.

Materials and Methods

The study was carried out close to Metema ($12^0$34'30''N and $36^0$18'16''E) northwest Ethiopia. The dominant soil types are lithosols on hilly areas and vertisol on plain areas. Ten-year average agrometeorological data is summarized (Figure 1).

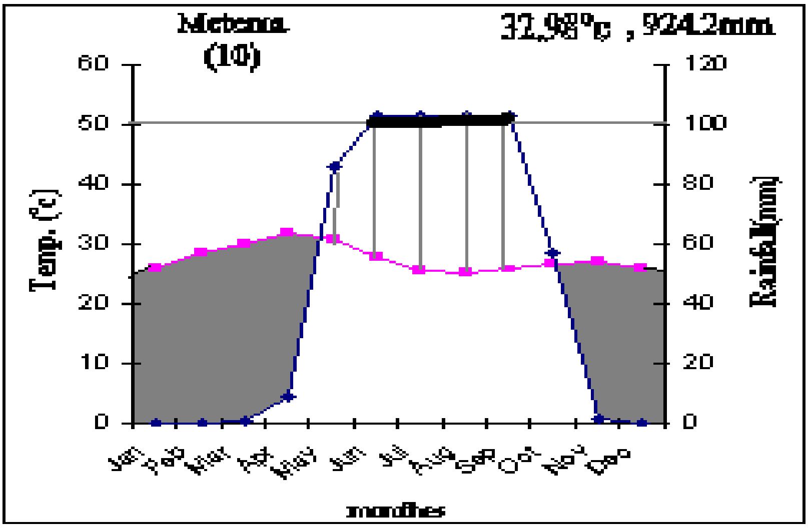

Figure 3. Meteorological diagram of Metema district (Source: Haile, 2009).

Up on preparation of cutting materials for vegetative propoagation study, healthy branches were obtained from a population of mature *B. papyrifera* trees in the adjacent forest, which have similar height, diameter, and environmental variables such as soils and microtopography. The cuttings were collected on four different dates between July 2003 and May 2004, taken during the time of planting and pit preparation. For each date, the experimental set up was a factorial combination of three factors:

- three levels of length of the branch cuttings (i)1 m, (ii)1.5 m and (iii) 2 m
- three levels of cutting diameters (i)10-15 cm, (ii)16-20 cm and (iii) 21-25 cm
- four levels of planting seasons (i) first week of May, (ii) second week of July, (iii) third week of October, and (iv) third week of March.

In each plot, 7 branch cuttings were planted in raw at a spacing of 2 m, and 4 m spacing has been used for between rows. Each branch cutting was planted in a pit that has a 50 cm depth and a cross section area of 90 cm^2. After planting the cuttings, a thorough ramming of the fine earth was done to eliminate air voids. In total 1,008 branch cuttings used. The duration of the study was six years.

We used the overall survival value taken at the end of the sixth year for analysis since there was no change in mortality after the 2004 rainy season. The number of branches and branch growth on a given tree was irregular that reflect the initial number of injuries or cut surfaces occurred during trimming branch cuts while planting material preparation (Online resource) therefore not used in the analysis.

The following model has been used for the data analysis

$$\mathrm{Y}_{ijk} = \mu + L_i + S_j + (L_i * S_j) + e_{ijk}$$

Where, μ the overall mean,

L_i effect of length of cutting material,

S_j effect of planting season,

$L_i * S_j$ effect of interaction of season and the length of the cutting and e_{ijk} random error.

Data were analyzed using the General Linear Model (GLM) procedures of SAS (2000). When there were no interactions and terms that were not significant in the full model, the reduced model was employed for analysis. The terms indicating the effects of diameter and its interaction with season of planting and cutting length were not included in the statistical analysis.

Results

The effect of planting season as well as its interaction with length of planting material on the survival of vegetatively propagated branch cuttings of *B. papyrifera* tree showed significant difference (Table 1).

Table 1. A. Least Square Means of survival (%) of branch cuttings of *B. papyrifera* with different cutting materials length (m) and planting season (month) **B**. Least Square Means of survival (%) across planting season (month) and corresponding F and P values, **C**. F and P values for the effect of cutting length, d. F and P values for the effect of interaction of planting season (month) and cutting length (meters)

(A)

Source	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
Model	15	142.1635860	9.4775724	3.70	<.0001
Error	71	182.0591704	2.5642137		
Corrected Total	86	324.2227564			

(B)

Source	DF	SS	Mean Square	F Value	Pr > F
Block	3	22.28049321	7.42683107	2.90	0.0410
Season	3	72.21816491	24.07272164	9.39	<.0001
Diameter	1	0.82067623	0.82067623	0.32	0.5734
Height	2	8.33657055	4.16828527	1.63	0.2040
Season*Height	6	38.50768113	6.41794686	2.50	0.0297

(C)

Season	Height	LSMEAN	SE	Pr > |t|
1	1	4.29324900	0.94618859	<.0001
1	2	5.83479812	0.66193478	<.0001
1	3	6.03599312	0.60725933	<.0001
2	1	6.64741830	0.56615078	<.0001
2	2	7.21377412	0.56615078	<.0001
2	3	8.22845633	0.56615078	<.0001
3	1	7.38496766	0.56615078	<.0001
3	2	8.58983185	0.56615078	<.0001
3	3	8.80102044	0.56615078	<.0001
4	1	7.94271541	0.60735196	<.0001
4	2	5.61197642	0.56615078	<.0001
4	3	6.45172079	0.56615078	<.0001

When planting season is considered, better survival was obtained from those materials prepared and planted in May followed by March, July and October with 71, 57, 46, and 22% mean survival values (Figure. 2).

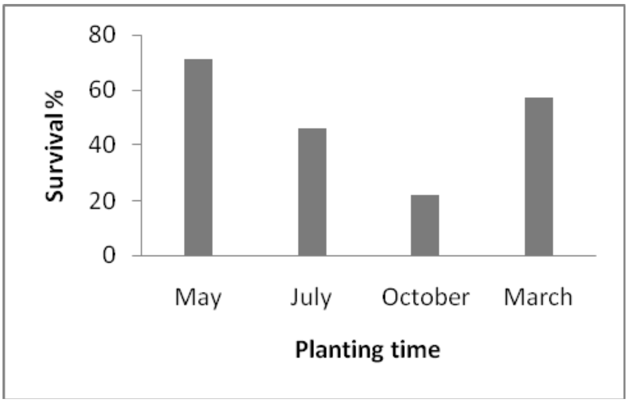

Figure 2 Mean survival value of different sized *Boswellia* cuttings across different seasons (months of the year) of cutting material preparation and planting time.

With regard to the effect of interaction of planting season and planting material length, the mean survival value for 1 , 1.5, and 2 m cuttings was 57, 75 and 80% in May, and 7, 27, and 32% in October, respectively. In March, greater than 50% survival was obtained only from 1.5 and 2 m cuttings with 54 and 70% mean survival value, respectively. In July, cuttings of length 1 m showed 57% survival, longer cuttings gave 33 and 46%. For a given planting material length, more survival was recorded when the planting season was changed. For instance, 1 m length cutting average survival in October was 7.14%, but for the same cutting length, the survival for May was 57.14%. The mean survival value of cutting length 2 m was 32% in October and 80% in May.

Planting in July did give better survival than planting in October, but in both planting seasons, average survival was less than 50%. Planting in October did give poor survival, and cutting size improved survival negligibly.

Although not significant (Table 2c) there is a general trend that larger planting materials did give better survival except when they are prepared in July. In July, smaller planting materials gave better survival than larger ones.

Discussion

The most important result from our experiment was that when branch cuttings of *B. papyrifera* are used for vegetative propagation plantation carried out towards the end of the dry season, specifically in May, will give above average survival (Figure. 2), and cuttings should be relatively longer to obtain more than 50% survival if plantation is in March. This result is in line with the traditional practice used by farmers for *Ficus* species in the study area.

In general, survival was improved from October through March to May with increase cutting length. However, with in a specific month the marginal survival improvement with increased cutting length showed diminishing trend. For instance, in the planting season of May, increasing planting material length from 1 to 1.5 m increased survival by 18%, but it brought only 5% improved survival when cutting length was increased from 1.5 to 2 m. Therefore, in case of shortage of planting materials, by restricting the planting season to May there will be a possibility to obtain enough short length propagules with little cost brought by mortality. If planting should be done in July, as it is the usual practice in Ethiopia, survival will be less than 50%. If this low survival could be tolerated, the cutting material should not be long. It should not exceed 1 m.

The higher mean survival value was observed from those materials prepared in March and May towards the end of the growing season; and lower in October towards the end of the rainy season, and July in the middleof the rainy season (Table 1). This may be from the accumulation and the composition of carbohydrates in cuttings or the rise of temperature as shown by (Leakey *et al*., 1982; Tchoundjeu *et al*., 2002; Leakey and Coutts, 1989). These seasonal variations support the observations of Danthu *et al.* (2002), that root cuttings were observed to root better when sampled while the ortet is dormant, rather than when in active growth.

Our result suggest branch cuttings of *B. papyrifera* can produce root after the ortet was matured, which is not the case with other plants (Greenwood, 1987. Husen and Pal, 2006; Husen and Pal, 2007). In the Afromonatne forests of Ethiopia, rooting ability of *Juniperus proccera* stem cuttings was also reported to diminish with age of the parent stock (Negash, 2002). This capacity of root formation on stem cuttings after the ortet was matured was suggested to be due to the presence of rooting system in the canopy (Danthu *et al*., 2002). Similar reports also commented the presence of relation between rooting system in the canopy and the ability of many species to regenerate from underground root suckers (Robinson, 1975; Danthu *et al*., 2002; Ofori *et al*., 1996). In the case of *Boswellia*, studies showed recruitment from root sucker was the source of almost all of the seedlings considered for their regeneration route in the same study area (Moges and Kindu, 2006; Abiyu *et al*., 2010). This implies that *Boswellia* might have effective auxin transport and storage, which make easy adventitious rooting of branch or stem cuttings.

Bond and Midgley (2001) differentiated regeneration strategy of forest tree species either recruiter or resprouter, recruitment by means of seeds or persistence by means of root sprouting. Recruiters maximize their fitness by ensuring they are reproductively mature before the next disturbance. Therefore, obligate seeders devote more resources to growth and reproduction. Whereas resprouters devote more resources to below-ground storage structures to facilitate resprouting following disturbance (Bell and Ojeda, 1999; Bellingham and Sparrow, 2000; Bell, 2001; Bond and Midgley, 2001), and devote proportionally larger amounts of root tissue to starch storage than do obligate seeders (Pate *et al*., 1990; Verdaguer and Ojeda, 2002). Similarly, *B. papyrifera* may maximize its fitness by allocating resources to structures that increase its chance of surviving the next disturbance through persistence by means of root sprouting. This implies, it invests disproportionally greater amount of time and resources for this purpose at the expense of growth, which will make the species vulnerable to browse and high seedling mortality. However, the major recruitment limitation in *Boswellia* was seedling mortality from drought or browse (Gebrehiwot *et al*., 2003; Ogbazghi *et al*., 2006; Negussie *et al*., 2008). Therefore, for immediate assisted restocking of *Boswellia* woodlands, planting long vegetative stakes that can withstand drought and above browse height of small ruminants will be a good working technology.

Our result also suggest vegetative propagation of *Boswellia* by means of branch cuttings may not need extended nursery life and plant growth regulators treatment that stimulate adventitious root formation. This will be an alternative option from earlier recommendations (Negussie *et al*., 2009) treating stem cuttings with latex from *Euphorbia abyssinica* to stimulate root growth.

Tapping *Boswellia* tree for frankincense production and its impact on asexual reproduction need research attention. Earlier reports showed tapping affect sexual reproduction. For instance, non-tapped trees produced three times as many healthy and filled seeds than tapped trees, and germination was higher than 80% for non-tapped and less than 6% for tapped trees in Eritrea

(Ogbazghi et al., 2006). However, little is known how tapping affect asexual reproduction and health of mature trees. Tapping should be investigated in relation to auxin transport and storage. This is because; tapping deep may cause injury on the phloem and vascular cambium.These plant tissues frequently injured during tapping are reported to be initiation points of adventitious root from stem cuttings in other woody plants (Davies et al., 1982). Therfore, an implicaton of such facts need to be cheached in to *Boswllia* as well.

Conclusion

Survival of branch or stem cuttings of *B. papyrifera* for vegetative reproduction largely depends on planting season, substantiating the empirical knowledge from Ethiopian farmers practice to propagate *Ficus thonningii*. For future plantation activities, size of cutting material should not be of concern so long as planting season is restricted to May and 70% average survival is targeted. However, with the current reality of free range grazing, using longer vegetative stakes above the browse height is recommended. Cuttings from *Boswellia* for vegetative propagation may not need treatment with plant growth regulators to stimulate root formation. The proposition that *B. papyrifera* is a resprouter will probe important research questions such as the relation between the oleo-gum-resin material transport and storage, tapping to harvest frankincense and the formation of adventitious roots on its branch and stem cuttings. Additional research is needed on the relative advantage of either using branch, stem or root cuttings for vegetative propagation.

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Regeneration of Gum and Resin Bearing Species in Rayitu and Sawena Disricts of Bale, Southeast Ethiopia

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Introduction

The Dryland environments of Ethiopia despite their harsh environmental conditions that limit the livelihood options of the community are home for woody vegetation resources that provide additional opportunity for livelihood improvement of the local community. Oleo-gum resins including gum arabic, gum talha, frankinscence, and myrrh are some of the products increasingly used in pharmaceuticals, food, flavors, liqueurs, beverages, cosmetics and perfumery, (EFAP 1994; FAO 1995; Lemenih and Teketay 2003a; Lemenih and Teketay 2003b; Lemenih and Teketay 2004; Lemenih *et al*., 2004; Gindaba *et al*., 2007; Tadesse *et al*., 2007). Certain plant species of the genera *Acacia*, *Boswelia,* and *Commiphora* are widely used for the production of oleo-gum resins especially gum arabic, frankincense, and myrrh. Thus, promoting oleo-gum resin production can contribute to the development of local and national economies and to the conservation and sustainable development of these Dryland ecosystems (Lemenih *et al*., 2004). Distribution and regeneration of the species producing these products vary spatially (Lemenih *et al*., 2007). Despite the fact that Ethiopia used to export oleo-gum resin products, investigations made into the production potentials and limitations were concentrated to few explorations of resource base and socio-economic significance (Lemenih et al. 2004; Lemenih and Teketay 2003a; Lemenih and Teketay 2003b; Eshete *et al*., 2005; Lemenih *et al*., 2007; Gindaba *et al*., 2007; Tadesse *et al*., 2007) and regeneration of few species (Eshete *et al*., 2005; Lemenih *et al*., 2007; Gindaba *et al*., 2007 *et al*., Eshete, 2011). The *Acacia - Commiphora* woodland vegetation in the Drylands of Bale constitutes various species used as sources of oleo-gum resin products. However, information on the distribution and regeneration ecology of these species is lacking. The present study was conducted with the objective of determining density and population structures of gum and resin bearing tree species to serve as a basis for management, conservation and sustainable utilization of the species.

Materials and Methods

Study site and species

The present study was conducted in the *Acacia - Commiphora* woodland vegetation of Rayitu and Sawena districts, Bale zone of Oromia Regional State, southeast Ethiopia. Both districts are bordering the lowland areas of Somali Region in the east and southeast, East Hararge in the east and the highlands of Bale in the North. The topography is dominantly plain (75%), sloppy (13%) and gorge (12%). In Rayitu district, the climates is generally characterized by low precipitation and high temperatures with mean annual rainfall of 500 – 700 mm and mean annual temperatures of 26 ^{0}C – 40 ^{0}C (PADS, 2004). In Sawena, mean annual temperature ranges from 16^{0}C to 32^{0}C during the rainy season and 32 ^{0}C to 40 ^{0}C during the dry season. The mean annual rainfall ranges between 600 and 800 mm. There are two rainy seasons in Sawena with the long season from mid March to mid May and the short one occurring from mid September to mid November. The gum and resin-bearing species studied are described in Table 1 below. The community depends on livestock production and some practice of farming as their livelihood strategies. Livestock product followed by sorghum and maize is the main source of food for all wealth groups.

Table 1. Gum and resin bearing tree species studied for their regeneration status.

Scientific name	Family name	Local name
Acacia mellifera	Fabaceae	Bilaala
Acacia Senegal	Fabaceae	Saphansa
Boswelia microphylla	Burseraceae	Mugloo
Boswelia neglecta	Burseraceae	Dakkara
Commiphora Africana	Burseraceae	Iddaa
Commiphora baluensis	Burseraceae	Hagarsuu
Commiphora confuse	Burseraceae	Hameessa
Commiphora guidoti	Burseraceae	Unsii
Commiphora myrrh	Burseraceae	Qumbii
*Commiphora species (Marade *)*	Burseraceae	Maraadee
Commiphora species (Xila)*	Burseraceae	Xiillaa

* *Afaan oromoo.*

Data collection

Data collection took place from May 24 to June 6, 2009. In order to determine density and population structure of the species, 71 sample quadrats of 20 m x 20 m were placed in transect lines of 1 km long following Kent and Coker (1992). Eleven transects of six quadrats each and a transect of five quadrats were laid parallel across the slope. Distance between quadrats and transects was 200 and 400 m, respectively. In each quadrat, Diameter at Breast Height (DBH) and height of every individual of the 11 gum- and resin-bearing species were measured using chain meter and bamboo stick, respectively. DBH was measured for individuals with ≥ 2 cm DBH and height for all individuals of the species including seedlings, saplings, and trees.

Data analysis
Density (the number of individuals of gum and resin-bearing species) per ha was calculated from the total number of individuals of the species recorded in the area. To analyze the population structure of the species, all individuals of each species encountered in the plots were grouped into arbitrarily defined height classes and histograms were developed using the height classes versus the number of individuals categorized in each of the classes using Microsoft Excel Computer software.

Results and Discussion

Density, DBH, and Height growth
Density considerably varied among the gum and resin-bearing species ranging from 3.87 ± 4.2 to 353 ± 99.5 stems per ha. *C. myrrha* is the dominant tree species followed by *A. senegal* and *C. africana* (Table 1). On the other hand, *Marade (Commiphora species)*, was represented by very few individuals. A high density of *A. senegal* and *C. africana* was reported from else where (Worku *et al.*, 2012). Similarly, the mean DBH and height varied among the species with the range from 3.37± 0.36 to 19.04 ± 7.66 and from 1.89 ± 0.30 to 7.87 ± 1 for DBH and height, respectively. *C. guidoti* is the highest in terms of DBH and height while *C. africana* is the least. Analysis of DBH and height growth showed C. *baluensis* and *Marade (Commiphora species)* were the next largest species in DBH and height to *C. guidoti*.

Table 1. Mean (± SE) density, DBH and height of gum and resin-bearing species in two districts of Bale Zone

Species	Density /ha	DBH (cm)	Height (m)
A. mellifera	264 ± 62.29	7.32 ± 0.36	4.57 ± 0.2
A. senegal	323.9 ± 116.81	4.12 ± 0.36	4.12 ± 0.38
B. neglecta	27.46 ± 31.04	9.52 ± 4.07	5.52 ± 1.56
B. microphylla	77 ± 29.85	4.64 ± 0.57	4.15 ± 0.55
C. africana	296.5 ± 96.51	3.37 ± 0.36	1.89 ± 0.30
C. baluensis	67.25 ± 25.95	14.2 ± 1.56	5.94 ± 0.47
C. confusa	26.4 ± 14.13	5.52 ± 1.05	3.51 ± 0.51
C. guidoti	44 ± 43.78	19.04 ± 7.66	7.87 ± 1
C. myrrh	353 ± 99.5	9.3 ± 0.8	4.46 ± 0.32
Marade (Commiphora species)	3.87 ± 4.2	13.47 ± 17.33	5.65 ± 3.72
Xila (Commiphora species)	225.7 ± 89.95	8.14 ± 0.94	4.39 ± 0.39

Population structure

Population structure differed among the gum and resin-bearing species. Based on similarities of their population structures, the study species were categorized into four groups with different patterns. The first group exhibited a typical inverted J-shaped curve, i.e. species having many individuals at the lower height classes and decreasing number of individuals at successively higher height classes. *C. africana, B. Microphylla and C. confusa* exhibited such a pattern with no or few number of individuals towards higher size classes (Figure. 1). *C. africana* had the highest seedling density compared to others. A similar result was reported by Worku *et al.* (2012) on seedling density of *C. africana* in Borana, southern Ethiopia .The second group showed a bell-shaped pattern with large number of individuals in the middle height classes and gradual decrease towards lower and higher height classes (Figure 2). To this group belong *Acacia mellifera*, *A. senegal* and *Commiphora myrrh.* The third group shows J-shaped curve with the highest density in higher height classes. Two *commiphora* species locally known as *Marade and Xila* demonstrated such a pattern (Figure. 3). The fourth group consisting *B. neglecta*, *C. baluensis* and *C. guidoti* demonstrated large number of individuals in higher height classes with no individuals in lower classes (Figure. 4). *C.guidoti* lacked individuals below 6m while *B. neglecta* and C. *baluensis* lacked individuals below 4m height. This could be attributed to cattle grazing and medium height classes of *C. guidoti* were also selectively felled for its bark.

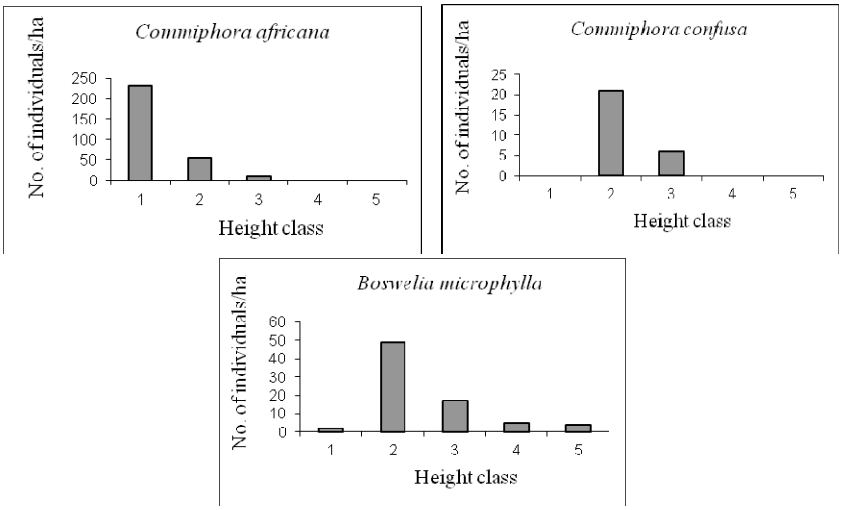

Figure 1. Height class distribution of individuals of *C. africana, B. Microphylla and C. confusa*; height classes: 1 = 0-2; 2 = 2-4; 3 = 4-6; 4 = 6-8; 5 = 8-10.

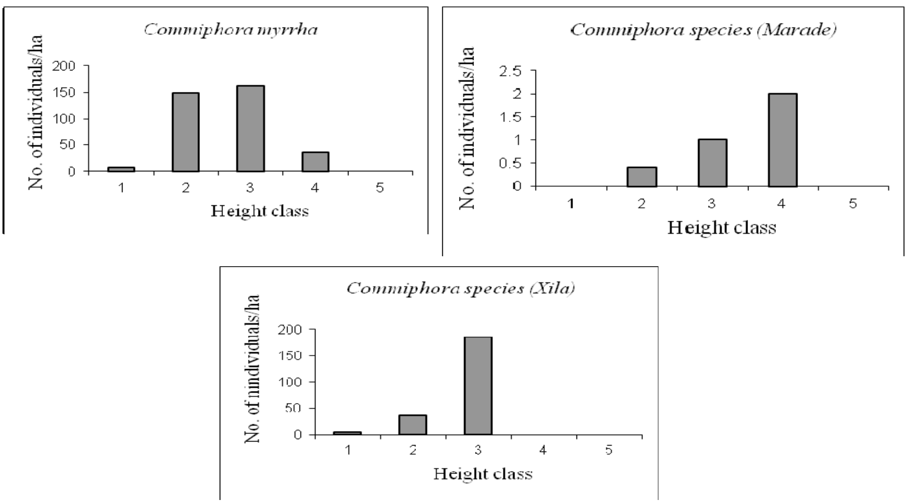

Figure 2. Height class distribution of individuals of *A. mellifera*, *A. senegal* and *C. myrrh;* height classes: 1 = 0-2; 2 = 2-4; 3 = 4-6; 4 = 6-8; 5 = 8-10.

Figure 3. Height class distribution of individuals of un identified Commiphora species (*Marade and Xila*); height classes: 1 = 0-2; 2 = 2-4; 3 = 4-6; 4 = 6-8; 5 = 8-10.

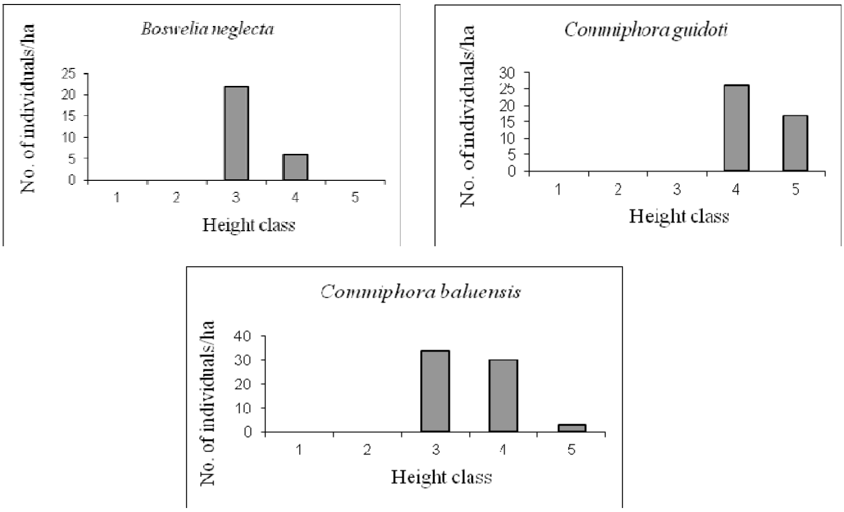

Figure 4. Height class distribution of individuals of *B. neglecta*, *C. baluensis,* and *C. guidoti;* height classes: 1 = 0-2; 2 = 2-4; 3 = 4-6; 4 = 6-8; 5 = 8-10.

Conclusion

The present study showed that the eleven gums and resin bearing species studied for their regeneration status considerably varied in density and population structures. The high densities observed in *C. myrrh, C. africana* and *A. senegal* would add value to the vegetation as these species provide products that contribute to local and national economies. Nevertheless, low densities observed in *B. neglecta* and *B. microphylla* together with the lack of regeneration in majority of the species calls for management interventions such as reduced selective removal of some individuals for fuel wood and construction purposes. On the other hand, a reverse J-shaped distribution that was observed in group I species in this study is an indication of healthy and stable regeneration. The bell-shaped and other distribution patterns (groups II-IV) imply hampered regeneration that could be attributed to cattle grazing, selective cutting for construction and fuel wood, as well as the biology of the species. The local community and the government should be aware and take tangible and sustainable measures on the resource base and its significance to local community as well as the national market. Alternative land use systems in the form of agricultural investment should no target the woodland vegetations. Reproductive and seed biology of *B. neglecta*, *C. baluensis,* and *C. guidoti* needs to be further studied in search of mechanisms for improving regeneration and seedling recruitment.

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Appendix 1. Woody species found in association with the gum and resin bearing species.

Scientific names	Family	Local name	Growth habit*
Abutilon hirtum (Lam.) Sweet	Malvaceae	Bulaan bulcha	S
Acacia reficiens wawra	Fabaceae	Sigirsoo	S
Acacia bussei Harms ex sjÖstedt	Fabaceae	Haalloo	T
Acacia oerofota	Fabaceae	Ajoo	S
Acacia robusta Burch. subsp. *usambarensis* (Taub.) Brenan	Fabaceae	Uttee	T
Acacia species	Fabaceae	Qaansaa	T
Acacia tortlis (Forssk.) Hayne. subsp. *spirocarpa* (Hochst. ex A. Rich.) Brenan	Fabaceae	Dhaddacha	T
Asparagus scaberulus A. Rich.	Asparagaceae	Sariitii	S
Balanites pedicellaris supsp. Somalensis Mild br. and Schlecht.	Balanitaceae	Liqimmee	S
Boscia angustifolia A. Rich. var. *angustifolia*	Capparidaceae	Qanqalcha	S
Boscia senegalensis Lam. ex Poir.	Capparidaceae	Darguu	S
Cadaba farinosa Forssk.	Capparidaceae	Meegaga	T
Carphalea glaucescens (Heiern) Verdc. *supsp. glaucescens*	Rubiaceae	Qardii	S
Combretum aculeatum Vent.	Combretaceae	Hurufoo	S
Commiphora samharensis Schewent.	Burseraceae	Qanqanaa	T
Commiphora monoica Vollensen	Burseraceae	Haadha gobee	T
Croton dichogamus Pax	Euphorbiaceae	Maakaftaa	S
Delonix elata (L.) Gamble	Fabaceae	Shukkeellaa	T
Un identified species			S
Dichrostachys cinerea (L.) Wight and Arn.	Fabaceae	Jirmee	T
Dobera glabra (Forssk.) Poir.	Salvadoraceae	Aadee	T
Entada leptostachya Harms	Fabaceae	Dhangaa gaalaa	C
Erythrina brucei Schweinf.emend.Gillett	Fabaceae	Waleenaa	T
Euphorbia burgeri Boisss.	Euphorbiaceae	Ciiraa	T
Grewia bicolor Juss	Tiliaceae	Harooressa	S
Grewia erythraea Schweinf.	Tiliaceae	Qacalee	S
Grewia mollis Juss.	Tiliaceae	Ulee qaalluu	S
Grewia species	Tiliaceae	Shukuumaa	S
Grewia velutina (Forssk.) Vahl	Tiliaceae	Haraanqoo	S
Grewia villosa Willd.	Tiliaceae	Ogomdii	S
Ipomoea trifolia Forssk.	Convolvulaceae	Lookatoo	S
Kirkia burgeri Stannard subsp. *Burgeri*	Simaruabaceae	Musdhugaa	T
Lannea triphylla (A. Rich.) Engl.	Anacardiaceae	Handarakkuu	T
Ochna inermis (Forssk.) schweinf ex Penzig	Ochnaceae	Elelenqaa	S
Sesamothamnus rivae Engl.	Pedaliaceae	Dareessa	T
Sterculia setigera Del.	Sterculiaceae	Qararii	T
Terminalia polycarpa Engl. and Diels	Combretaceae	Hererrii	T
Terminalia species	Combretaceae	*Digdigsaa*	S

** T= tree; S= shrub; C= climber.*

Socio-economic Contributions of Gums and Resins

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Introduction

Non-timber forest products (NTFPs) such as gum and resins play a significant role in economic development of a nation. Majority of rural households make use of NTFPs for different purposes ranging from food, medicine, and income generation. Among the ranges of NTFPs, gum and resins (frankincense, myrrh, opoponax, gum arabic, gum talha and gum karaya) are commercially important resource in the arid and semi-arid regions of Sub-Saharan Africa with potentials for spurring economic development of the nation and rural community (Adefires *et al*., 2011; Habtemariam *et al*., 2011; Mulugeta and Habtemariam, 2011). Gum and resins are produced in the rural (remote) areas, traded in urban centers and used in some of the sophisticated cities in the world (Mulugeta *et al*., 2003; Mulugeta and Demel, 2004; Adefires *et al*., 2006). They touch wide ranges of human lives and cross-sections in the society. Sound development of these commodities will thus have a huge impact on vast population, especially, the poor and vulnerable groups of communities living in the rural areas of developing nations.

As the existing few studies disclosed, arid and semi-arid regions of Ethiopia have the biggest potential in east Africa endowed with huge resources of oleo-gum-resin bearing species of the genera *Acacia, Boswellia, Commiphora,* and *Sterculia* which produces economically important commodities such as gum arabic, gum talha, gum karaya, frankincense, myrrh and opoponax (Mulugeta *et al.,* 2003; Adefires *et al*., 2006). The country is estimated to have over 3.5 million ha of woodlands and bushlands with an estimated 300,000 tonnes of gums and resins production potential, although currently small proportion of this potential is tapped annually (Mulugeta and Demel, 2004). Survey of export statsicts showed that at the national scale, between 1996 and 2003, Ethiopia exported 16,019 tonnes of natural gums (gum arabic, frankincense, myrrh and opopanax), which worth 20,473,058 USD (Mulugeta, 2005). At local level, gum and resin collection and sale is identified as one of the major livelihood activities in various dryland regions in the country. For instance, according to Mulugeta *et al*. (2003), it ranks second just next to livetsock production in

Liben zone of Somali region. It ranked second and third in Arero and Yabeleo districs of Borena zone respectively (Adefires, 2006).

Owing to dryland environmental conditions, livestock production is the major occupation for much of the population residing in arid and semi-arid regions in Ethiopia with few subsistent farming practices at various parts of these regions (Mulugeta *et al*., 2003; Gemedo, 2004; Adefires, 2006). The erratic and scanty rainfall pattern and lack of even a single rainy season in most parts of these regions, however, leads to frequent failure of livestock sector (the major economic activity) and the subsistent farming leads to tragic hunger crises of the pastoral and agro-pastoral communities. More importantly, the pastoral and agro-pastoral communities are remaining to be the primary victims of natural hazards and the consequent famines. For instance, the recurrent droughts have made the traditional coping mechanisms, which were relatively effective earlier inadequate (Gemedo, 2004; Adefires, 2006). Therefore, it is apparent to look for alternative options that help to diversify the livelihood of the pastoral and agro-pastoral communities and national economy at large. Luckily, these regions are endowed with vast woodland vegetations that give additional opportunities to avert the prevailing food insecurity situations while maintaining the integrity of the environment (Mulugeta *et al.,* 2003; Abeje *et al*., 2005; Dagnew, 2006; Adefires *et al*., 2007). In the broader sense, gum and resins are used for several industrial purposes (Toure, 2009).

In order to evaluate the economic importance of NTFPs, there is a need to answer the economic questions of NTFPs what is the potential value of NTFP resources?; what is the actual contribution of NTFP production to national and household income?; and how much is the potential profitability of NTFP enterprises?

Examples to answer these questions (Neumann and Hirsch, 2000) are

- in India as a whole, NTFPs production contributes about 40% of total official forest revenues and 55% of forest-based employment. In Madhya Pradesh, India, the collection and sale of NTFPs accounts for between 40% to 63% of total annual income of the rural population and provides an important income generating activity to offset seasonal unemployment rate;
- recently, the government of Botswana has recognized that the value of NTFPs exceeds that of timber exports;
- in Guatemala, the harvest of three NTFPs items (chicle gum, allspice and xate palm) produces between four and seven million dollars in export income per year;

- although multiple costs and proximity to market determines the profitability of NTFPs enterprises, the increasing demand for NTFPs in the international market can compensate this; **and**
- NTFPs products are used in different industries and their market price has been increasing from time to time. This indicates their potential value in the current market (CIFOR, 1998; AFC, 2004).

The reasons why increased attention paid to NTFPs in recent times are (Leakey, *et al*., 1996; Pérez and Arnold, 1996; Neumann and Hirsch, 2000;Marshall *et al*., 2006)

- First, heightened interest in the value of biodiversity, carbon sequestration and other environmental functions provided by forests, and associated concerns with the consequences of the use of forests in ways that lead to their destruction or degradation. A perception that management for NTFPs is more compatible with sustainable use of forests than management for timber or shifting agriculture has consequently been one of the more powerful factors in stimulating heightened interest for NTFPs; and
- Second, the growth in awareness to use or sale of NTFPs form important parts of the livelihood systems of very large numbers of people.

This has given rise to a notion that sustainable management of forests for these products should therefore have valuable welfare consequences, as well as being environmentally sound - encouraging the idea that in this way environmental and developmental goals can be pursued jointly.

Objectives of the study:

- To describe and assess the operation and strategies of the existing market, the stakeholders involved in the market chain and their respective roles and benefits;
- To quantify the value added gained as products moves along the market chains;
- To assess the impact of product quality, quantity, seasonality on marketability of products;
- To identify existing and potential local and international markets and traders and conditions to access these markets;
- To quantify the potential contribution of gum-resins products to household livelihood and national economy;
- To document on the existing formal and informal institutional arrangements facilitating and/or hindering production and marketing of gum-resins products.

Materials and Methods

Assessment sites

Questionnaire survey has been conducted at Metema and Quuara in Amhara Regional State; Yabelo and Negele Borena in Oromia Regional State; Filtu woreda of Liben zone in Somali Regional State; Humera, Kola Temben, Sheraro and Abergele in Tigray Regional State; Pawe in Benshangul-Gumuz Regional State and Addis Ababa and Nazareth for gums and resins with stakeholders involved in the sector.

Assessment approaches

Group discussion at regional, zonal and district levels: Intensive discussion has been made with mangers and experts of both government and NGOs on the basic issues regarding the sector. Highly hot spot areas of gum-resins growing pockets have been selected for household interview and observational assessments. The reasons for selecting the specific sites for the study assessment were

- engagement of households in the sector is common practice in the sites;
- close connection of these products to household livelihoods in the sites;
- diversity and abundance of resources; and
- existence of government and NGOs initiatives in the sector in those sites.

Collection of relevant documents and statistics: In the group, discussion it had been briefed to the stakeholders the objective of the study and after they understand it well the desired data were provided to the assessment team. Data on resource situation and existing policy and strategy were collected from regional, zonal and district level bureaus and offices (totaling more than 30): Agriculture and Rural Development Bureaus, Trade and Industry Bureaus, NGOs offices and NGMPE sub-offices. Statistical data for export and domestic markets were collected from Ethiopian Revenues and Customs Authority (ERCA) and Natural Gums Marketing and Processing Enterprise (NGMPE).

Survey and interview at village level: Since farmers and pastoralists are the implementers and direct beneficiaries of the gum-resins sectors, households were selected randomly that the number of households were based on the homogeneity of the population, i.e. if the population of a particular pocket area is more or less homogeneous less number of households had been considered for interview. Accordingly, 135 households for selected pocket gum-resin bearing treess growing areas were interviewed. The survey was directly focused on collecting information on the opportunities and challenges in the sector, annual cash income contribution from gum-resins for households and the chains of marketing, supply and processing of such products.

Interviewing enterprises, cooperatives and firms: One gum-resin marketing enterprise and twenty gum-resin based cooperatives mangers and some members had been interviewed to provide information on marketing, processing, collection and the general opportunities and challenges excising in the country in general and at enterprise and/or firm level in particular.

Results and Discussion

Demography of gum and resins collectors

Age class distribution of the 135 households is indicated in Table 1. In the gender perspective, 94.1% of the households involved in gum-resin tapping and collecting are men and while the remaining are women. Of the total households surveyed, 51% are illiterate and 41% and 8% of the households have educated up to primary and secondary level, respectively.

Table 1. Involvement of respondents in gum-resin business by age category

Age category	Frequency	Percent
< 20	9	6.7
20-30	36	26.7
30-40	40	29.6
40-50	34	25.2
> 50	16	11.9
Total	135	100.0

Institutional arrangements in gums and resins utilization

It was understood from questionnaire survey that 52% of the respondents agreed as they have user right to collect gum and resin products from gum and resin-baring species while the remaining claimed, asthey do not have it. Twenty-nine per cent of the respondents replied that there is limited institutional means to assure user right to gum and resin bearing resources. However, 52%, 15% and 4.4% of the respondents, respectively, have responded that local bylaws, national-regional policy, and land certification are the possible institutional arrangements that can facilitate the affirmation of user right to collect gum and resin products at the current condition. Regarding the occurrence of conflict in the use of gum-resin resources 39.3% of the respondents have replied that conflict is none existence while 29%, 24.4% and 7.4% of the respondents claimed the occurrence of conflict at low, high and medium levels, respectively. Forty-one per cent, 4% and 56% of the respondent households, respectively, asserted that customary, national legal and alternative systems of institutional arrangements are the means of conflict resolution in the use of gum-resin resources at the present situations.

Gums and resins in local economy

Gum-resin production and marketing contribute a lot in the local economy in various regions of Ethiopia. For instance, in the year 2010 the three districts, namely, Kola Temben, Tahitay Adiyabo, and Kaftah Humera in the Tigray National Regional State the annual average revenue from gum-resin was 9,691,530Birr. Similarly, from the year 2002-2010 seven gum-resin cooperatives (holding 445 members) including the Ethiopian Natural Gum Processing and Marketing Enterprise in Humera district had collected 2305.855 tonnes of gum-resin and get an average revenue of 26,472, 853Birr. In the case of Southeast Ethiopia (Guji and Liben zones) the ENGPME alone had collected 930.23 tonnes of gum-resin which can add revenue of 21,550,290 Birr in the year 2008-2010. At the same time, the Moyale district Trade and Industry Bureau of Somali Region had collected 133,504 Birr tax from gum-resin traders in the years 2005-2009.

The assessment of seven cooperatives with 320 members that are organized in gum-resin business in Liben and Guji zones (southeast Ethiopia) has shown that they were established with average initial capital of 3,341Birr per cooperative in 2005 and moved up to an average capital of 33,477 Birr in 2010. The average gum-resin price during those times at the conventional market was 17,000 Birr/tonne while the cooperatives sold the same amount at 21,000 Birr, which enable them to get a premium profit of 4,000 Birr/tonne. In Metema district, the Trade and Industry Bureau had collected a royalty fee of 730,330.66 Birr in the years 2004 – 2009 form the organizations involved in the gum – resins business who have an average annual harvesting capacity of 18,471.03 kg in the indicated years. In Quara district too, a single cooperative having an annual average production capacity of 20 tonnes had paid annual royalty fee of 156,000 Birr in 2009.

The field survey has shown that there was high dependency of households (Table 2) on gum and resin products for their cash income (13.4% of annual cash income) and there is correlation between income source options ($0.23 \leq r \leq 0.74$).

Table 2. Household category for cash income options in gum-resin growing areas of Ethiopia

Cash income options	Household category					
	Engaged		Not engaged		Total	
	N	Percent	N	Percent	N	Percent
Crop production	129	95.6	6	4.4	135	100
Livestock	123	91.1	12	8.9	135	100
Gums and Resins	126	93.3	9	6.7	135	100
Off farm activity	47	34.8	88	65.2	135	100
Other NTFP-honey	18	13.3	117	86.7	135	100

Gum and resin business sector also contribute a lot in income generation for households. For example, in 2010 at ENGPME alone there were more than 2000 casual workers mainly women for separating the products according to their grades. The workers were paid birr 1.50/kg and a man/woman can process up to 20 kg per day (which equals 30 Birr/day). The enterprise also has 300 permanent staffs including technicians and up to high-level managers. The number of causally employed workers in gum and resin collection at each collection site is also in thousands.

Impacts of seasonal variation in gums and resins production and marketing

Seasonal variation can affect production, price, quality, and marketability of gum-resin products (Table 3). For example, during field assessment at Humera district we have observed that frankincense collected from the resource base had to be stored in the district warehouse and stayed for long due to long and bureaucratic management process from the district administrative body to transport the product timely. Upon long stay in the warehouse, the frankincense would turn from white to yellow colour due to existing high temperature in the area. As a result, the product loss international market demand (which requires a uniform and constant quality) and would be sold for local market with low price.

Gum-resins activities are more or less seasonal: in this case, households are more likely to switch from these activities to other livelihood options. This is because households desire for a more consistent and year-round source of income. Having a specialized market niche and good product quality can help to protect the substitution of a product by an alternative one. Tappers from Tigray explained that the production of gum and resins particularly depends on the optimum temperature and good rainfall distribution in a particular year and specific area and those in Moyale district have classified January – March as season of primary gum-resins production and June – July as secondary.

Table 3. Seasonal variation on marketability of gum and resins products in Ethiopia

Season	Effect on oleo-gum resins activity	Oleo-gum resin collectors response
Dry	• High production • High quality product • High income generation • Easy for tapping and collection • Good price for market	• About 33% and 29% of the collectors responded March-May and September-November as season of better incense yield while 58% and 27% for March-May and June- August for better incense sell price, respectively.
Wet	• Low production • Poor quality product • Low income generation • Difficult for tapping and collection • Low price for market	• About 13% and 23% of the collectors responded December-February and June- August as season of better incense yield while 9% and 3% for September-November and December-February for better incense sell price, respectively.

Gum and resins in national economy

Gum-resins and bamboo products contribute a lot both to the household livelihood and national economy of Ethiopia. For instance, in the years 2001 to 2010 the ENGPME alone had exported 11,247.322 tonnes of gum-resin products and added 198,996,009.38 Birr to the national economy. The data obtained from ERCA has shown that Ethiopia has exported 6,174,354 kg of gum arabic and 33,864,574 kg of other gums and resins in the years 1997 – 2010 and gained an FOB (Free on Board) value of 696,857,546 Birr, *i.e.* PES (Price Elasticity of Supply) = 0.332 and the main importers of these products from Ethiopia were China and UAE (United Arab Emirates) with the share of 20.1% and 19% of the export, respectively.

At the same time, Ethiopia also imported 169,523 kg of gum arabic and 2,598,752 kg of other gums and resins in the years 2005 – 2010 and paid a CIF (Cost of Insurance and Fright) value of Birr 27,730,768 Birr, whereas collected a total tax of 17,024,363 Birr from this.

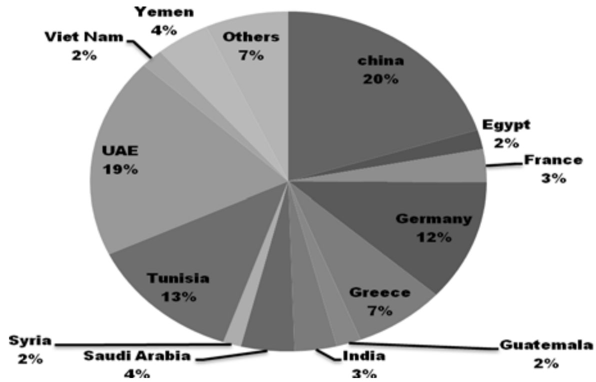

Figure 1: Major importers of NTFP from Ethiopia (%).

Gums and resins price, export and import trend

The analysis of export data from ERCA has shown that the gum and resin price both in domestic and international market was at an increasing trend particularly in the last three to four years (Figure. 2a, b). From the same analysis, even though the trade balances for gum and resin export and import market indicated surpluses, there is a general trend of decrease in the quantity of gum and resin exported and as well as imported (Figure. 3a, b).

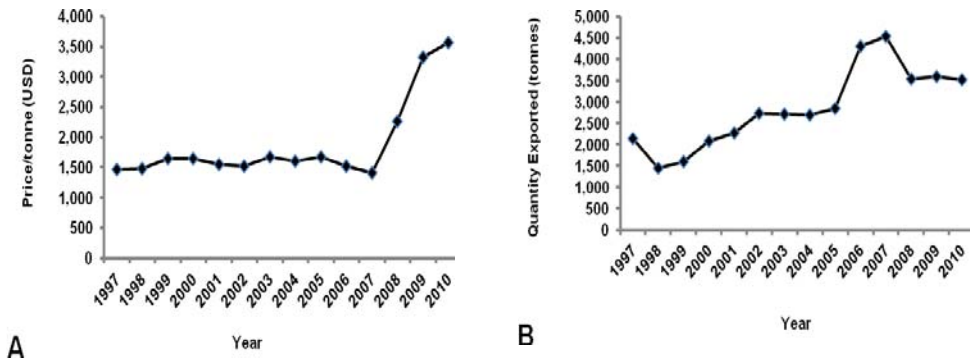

Figure 2: Price trend in birr (a) and quantity exported (b) of gum and resins export market by Ethiopia.

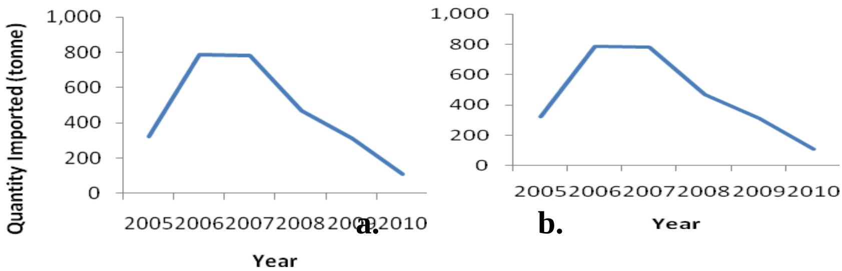

Figure 3: FOB, CIF and tax trends in birr (a) and quantity imported (b) of gum and resin products in Ethiopia.

Gums and resins value adding system

Tapping (production activity) → processing (cleaning activities) → sorting and grading → national and international markets. As the products moves up through this chain the relative weight of value added increases (Figure. 4).

Management cost (processing, storage, transport, labour and other miscellaneous cost) to supply one tonne of gum and resin through the above chain to export market is about 75 % of the selling price. The marketing margin between local marketing and export marketing was 3,750 Birr per tonne for the 2010 market for Tigray type incense (Table 4).

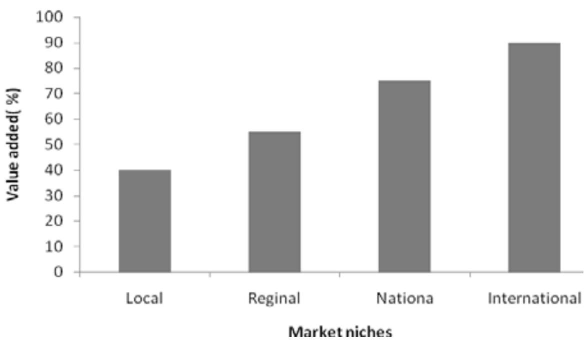

Figure 4: Relative weight of value added in the gum and resin marketing along the market chain.

Gum and reins grading criteria

Mechanically and manually: selecting the products according to color and size by using simple cultural tools and sieve of different size. There is no approval for the grades for quality and standard by the ERCA. The grading system is simply an agreement between the sellers and the customers.

Physical grading system: the main criteria to classify gums, resins, and incenses in Ethiopia are size, quality, and colour of the products. The red and coarse sized gum myrrh for example graded as first grade A and B, while less quality and small sized one graded from third to fifth grades. The white, quality, and coarse sized incense also graded with similar procedure. There is no chemical grading system until currently, but there is plan to do so in the future. The main criteria must be the chemical classification system, because both the small sized and coarse sized products may have the same chemical content. As a result, the physical classification system may lead to financial loss as the so called the lower grade products are sold at low price while having the same chemical content as that of the so called the high grade.

Table 4. Marketing margin of incense (Tigray type) – 2010

Market type	Selling price/tonne (Birr)	Total cost/tonne	Net profit/tonne	Margin
Local	15,000	11,250	3,750	
National	22,000	16,500	5,500	1,750
Export	30,000	22,500	7,500	2,000
Total marketing margin				**3,750**

The white arrows in the marketing loops for gum-resins in Ethiopia in figure 5 are just to indicate that the marketing integrations and the value chain at the level of processing and then marketing of processed products are very weak. The main upgrading in gum and resin marketing in Ethiopia that are recognized during the market assessment were:

- *Process upgrading* - an introduction of improved tapping tools such as Sudanese sunki for gum and resins tapping by COOPI (Cooperazione Internationale), were some of the initiatives of process upgrading observed during field survey;
- *Product upgrading* - examples of product upgrading observed during field survey includes diversifying from traditional incense products into packed and labeled ones such as “incenso nero”- balack incense and “incenso del deserto” – desert frankincense made in Ethiopia by COOPI which have very high value in niche markets;
- *Functional upgrading* - there are gum and resins producer’s cooperatives, in Tigray region and Guji and Liben zones for example, that take on new functions such as export marketing, or taking on new and more lucrative roles within the value chain;

- *Chain upgrading* - there are some initiatives to produce new products such as improved quality incense, which are not initiated previously, for marketing by establishing a new value chain.

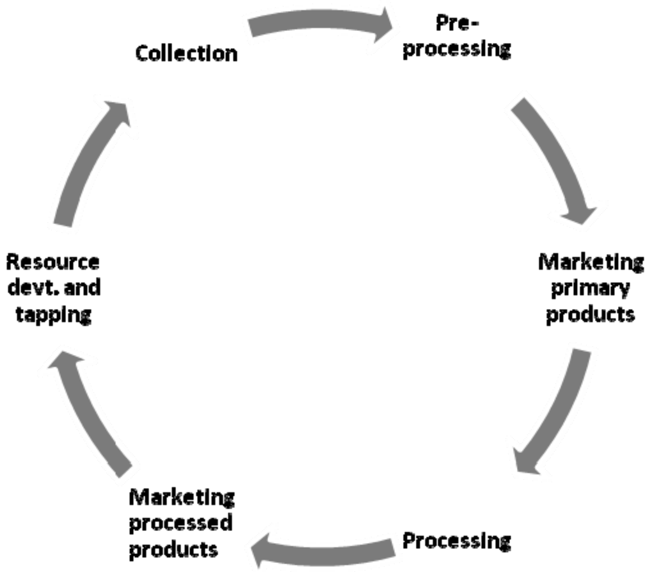

Figure 5. The marketing loop of gum and resins in Ethiopia

Challenges in gums and resins sector

The information from different stakeholders during the field assessment had indicated that the issues that negatively affect the marketing of gum and resins in Ethiopia in general and in gum and resin producing areas in particular are:

Anthropogenic and biological drawbacks

- Resource decline due to deliberate fire, deforestation for agriculture and settlement, firewood collection and overgrazing;
- Competition for the same resource and products;
- Decline in production, the tree cannot ooze easily when tapped;
- Lack of propagation methods for the species of *Bosewellia* and *Commiphora*;
- Low regeneration rate of the resource base;
- Gradual reduction in vigor of harvest plants;
- Decrease in rate of seedling establishment of harvest species;
- Poor pre-processing which can reduce the incomes of gum and resin gatherers and the sustainability of the resource and lower the product price due to inferior quality or reduce the saleable portion of the harvest, making it necessary for gatherers to harvest larger quantities;

- If gum and resins are not processed locally, they yield low returns;
- Collectors do not have access to market information; and
- Expansion of the gum and resins collection can result in overexploitation or the loss of access to the natural resource base.

Institutional drawbacks

- Existence of conflicts at border demarcation between different cooperatives;
- Administration bureaucracy in the taxing system;
- Less attention given to the sector and lack of tenure;
- Illegal trade and absence of market regulation policy at national level; and
- Rigid rules and regulations to transport the product

Economic drawbacks

According to information from suppliers and traders the marketing bottlenecks at Somali Region of Liben zone and Oromia Region of Guji zone includes the following:

- *Bartering*- due to poor marketing system bartering is widely practiced. During dry season many poor pastoralists came with natural gums and incense and get some sugar. This type of transaction, which hardly accommodates price fluctuations and inflation, affects the suppliers (*e.g.* 2 kg of incense for a kilogram of sugar).
- *Contraband trade*- gum and incense products are sold to Kenya with cheaper price.
- *Price fluctuation*- the price of gum and incense varies with season. It is attractive during the dry season and poor during the wet season.
- *Availability of different currencies*- there are currencies of Ethiopian Birr, Somali and Kenyan Shillings in the area. The existence of high fluctuation rates among these currencies may lead the gum and incense suppliers to high exploitations.
- *Role of the intermediaries* due to lack of marketing access and absence of strongly organized marketing cooperatives, the intermediaries maximizes their profit at cost of the suppliers.
- *Conflicts*- the existence of conflicts, between Somali and Borena for example, the suppliers may leave local markets and sell to Kenya with a lower price.

Obtainable claims in Humera, Kola Temben, and Sheraro

- Most of the members of the cooperatives are not farmers rather external traders and investors; hence farmers are not full beneficiary;
- Labour is brought from Adwa for tapping gum and resin which is far away from the resource base; hence the locals are not a beneficiary from employment generation; and
- The strategy don't allow individual farmers to tap gum and resin from their farm and rangelands, hence the farmers are damaging the resource base by cutting in response of that.

Opportunities in gums and resins sector

- High demand in the international markets;
- Increased interest in organic products in cosmetics and pharmaceutical industry;
- Resource development initiatives by regional governments;
- Initiative of organizing farmers in gum and resin cooperatives by regional governments to:
  - enable members to gain more powerful position in the value chain;
  - help members access to resources and that would enable them to add value at the source;
  - help members to obtain credit loan from bank;
  - help members to build their capacity in obtaining technical support and training from government offices and NGOs;
  - help members to increase their production and productivity by better managing the resource base;
  - enable members to get market access and rewarding profit than conventional traders, for example cooperatives organized by COOPI in Guji zone had sold a tonne of incense with 20,286 Birr in the year 2010 as compared to the conventional traders who had sold for 16,143 Birr.

Conclusions and Recommendations

- Setting policy at national level on how to use natural gum bearing tree species;
- Setting market regulation policy on natural gum products;
- Research on alternative propagation methods other than the existing ones which are not promising;
- Urgently, policy should be formulated on how to use gum bearing tree species. Research, education and extension services should give due attention synergistically to create better awareness and scientific bases to conserve the species and increase its production potential;
- Encourage the approval of quality certification which is not applicable in the country until now for gum and resin products;
- Enhancing rehabilitation rate by area closure;

- Cooperatives and investors should develop sustainable resource management plan and should hire a professional;
- Cooperatives should be formed on farmers based, because external traders are focused on their own benefit at the expense of the loss of the resource base;
- Other species such as *Stericulia spp*, *Acacia senegal* and *Acacia seyal* should be given due consideration in research, production system, technology and marketing; and
- Resource management, regulation, consumer characteristics, environmental and social issues must be fully addressed and incorporated into management and marketing strategies.

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Evaluation of Growth Performance and Gum Arabic Production of *Acacia Senegal* in Northwest Lowlands of Ethiopia

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Introduction

Global attention to Non-Timber Forest Products (NTFPs) has increased in the last three decads due to their compatibility with environmental objectives including the conservation of biological diversity, and their contribution to household economies, food security as well as to national economies (Booth et *al*, 1988; Neumann and Hirsch, 2000). NTFPs are biological resources of plant and animal origin, harvested from natural forests, plantations, woodlands and trees outside forests (FAO, 1995). Natural gums and resins are among the various NTFPs in the dryland resources that contribute to improved livelihoods of the many rural communities. These resources also contribute to the amelioration of the environment and hence for the sustainable management and development of the drylands, which favors the need for their development and sustainable utilization.

Ethiopian dryland natural vegetation resources harbor several species of commercially important species. The *Acacia*-*Commiphora* woodlands in the drylands of the country with their dominant *Acacia, Commiphora,* and *Boswellia* species are well known for their economically valuable gum and resin products such as gum arabic, frankincense, myrrh (Eshete *et al.,* 2005; Tadesse *et al*., 2007; Lemenih *et al*., 2011). The country is reported to be one of the world's largest producers of olibanum, however, the annual production of gum arabic is very minimal (Tadesse *et al.,* 2007; Lemenih *et al.,* 2011).

Acacia senegal (L) Willd (family Leguminosae, Mimosoidea) is one of the promising multipurpose tree species in arid and semi-arid areas of Ethiopia, which have various socio-economic and ecological benefits (Azene, *et al*., 1993; Jøker, 2000). The species is highly valued for gum arabic production (Andreson, 1990) in which the gum is exudated from trunks, branches, and twigs. The species is internationally designated source of gum arabic that is permitted for food use (Andreson, 1995). The product has a wider technological application in food industries, pharmaceutics, and other various industries. In addition to gum, *A. senegal* improve soil fertility and are used on a large-scale to control desertification. It also provides fuel wood, local construction materials, fodder from leaves and pods. It is highly suitable in agroforestry systems, for its nitrogen fixing ability in combination with agricultural crops (Cossalter, 1991).

A. senegal is variable and widely distributed tree species, recognized to occur in a range of defined species and varieties (Ross, 1979; Bernan 1983). The species naturally extends over a wide ecological range that differs in rainfall, soil and altitude in arid and semi-arid areas of sub-saharean Africa. It is naturally distributed in the traditional *'gum belt'* which occurs as a broad band across the sub-saharan Africa, from Mauritania and Senegal in the west to Sudan, Eritrea, Ethiopia and Somali in the east. In Ethiopia, natural stands of *A. senegal* are found in the *Acacia-Commiphora* woodlands in the western, southern and southeastern lowlands and *Acacia* woodlands in the Rift Valley region of the country (Azene*et al*., 1993). Varietal differences in *A. senegal* are based on variation in natural distribution as well as differences in morphological characteristics (Bernan, 1983; Cossalter, 1991). Accordingly, four varieties of *A. senegal* are recognized- *A. senegal* var. *senegal*, var. *kerensis* Schweinf*,* var. *leiorhachis* and var. *rostrat* Bernan (Ross, 1979) among which var. s*enegal*, var. *kerensis* and var. *leiorhachis* occur in Ethiopia (Azene et *al*., 1993). Commercial quality gum arabic is regarded to be produced from *A. senegal* var. *senegal,* which is widely distributed on the African continent (Brenan, 1983).

Despite the high potential of the resource base, currently the annual production and export of gum arabic from the country is very low (Tadesse *et al.,* 2007; Lemenih *et al.,* 2011). This is due to the lack of proper production technique. The current production is mainly based on collection of gum from natural oozes. Moreover, information/knowledge on the establishment techniques, yield and quality of gum from different provenances, optimum age for tapping, phenological records and silvicultural management requirements of the species are limited or otherwise lacking. Since *A. senegal* is an important cash crop for its valuable export product, there is a large interest in exploration and selection of provenances for the promotion of gum arabic production. This research was designed to fill the gap of knowledge and technology to utilize the available potential of natural stands of the species and promotion of selection of better performing and yielding provenances. The specific objective were: (i) to investigate the effect of tapping position and season on gum yield, (ii) to evaluate the gum yield of the species in the wild state and develop tapping techniques for gum production, and (iii) to investigate the variation in growth performance of local *A*. *senegal* provenances and select provenances for further promotion.

Materials and Methods

In this study we conducted two experiments in North-West lowlands of Amhara Region, namely Merab Armachiho and Metema Districts. The first experiment was aimed at evaluation of gum arabic yield from natural stands of *A. senegal* in Merab Armachiho (Abderafi area) tapped at different seasons and tapping positions and the second experiment was conducted in Metema district to evaluate the growth performance of six provenances of the species.

The study area

The yield trial was conducted in natural *A. senegal* stands in Abderafi area, which is situated at 985 km Northwest of Addis Ababa. The altitude of the area ranges from 550-950 m a.s.l. It receives mean annual rainfall of 885 mm. The mean annual temperature is 27.8°C and experiences mean length of 7 months dry season. The provenance trial was set up in Metema district located at 36°17' E and 12° 39 N' in North Gondar about 975 km Northwest of Addis Ababa. The altitude of the area ranges from 650-1100 m a.s.l. It experiences a mean annual rainfall ranging between 660-1130 mm. The mean minimum and maximum temperatures of the area are 19.1 and 35.6 C, respectively. Both areas are among the potential commercial crop production areas of the country.

Experimental Design, Data Collection, and Analysis

A 3 x 4 factorial randomized complete block design with three replications was used for the yield trial. Two factors, namely time/season and position of tapping were examined. The tapping seasons were three (mid October, mid November and mid December) whereas the tapping position had four levels: Lower stem (50-100 cm), Middle stem (100-150 cm), High stem (150-200 cm) Branches. Each treatment combination was applied to 5 trees in each block (60 trees per block and total of 180 trees was treated). The trees in the selected experimental site with relatively homogenous diameter were selected for the tapping experiment. Then, 180 trees were marked/ tagged and treatment combinations were then applied. Tapping was done with specially designed axe and “sunki”. During tapping, trees were treated in such a way to attain relatively similar depth, width, and length of strips.

The yield first and second collection/picking from each experimental tree was collected manually by hand. The gum yield from each picking was collected in a separate labeled paper bags and weighed using sensitive balance of high precision after drying at room temperature. The yield data was then analyzed by the Analysis of Variance using SPSS.

For the provenance trial, six local provenances of *A. senegal* were evaluated for the variation in growth performance and adaptability in Metema District. The provenances were given names relating to the geographic origin (name of the area of collection followed by the seed zone number) (Albæk, 1993). Although Wachile and Negele Borena are in the same seed zone we consider them as separate provenances due to the observed morphological difference of the *A. senegal* trees.

Table 1. *Acacia senegal* provenances and their corresponding seed zone considered in this study

Provenance code	Collection area	Seed zone number according to Albæk (1993)
AD 11-3	Abderafi, Northwest Amhara	11-3
AW6-1	Awash, Afar	6-1
Lan 10-1	Langano area, central Rift valley	10-1
NB9	Negele Borena	9
WAF-3.1	Worer, Afar	3-1
YB-9	Wachille, Yabello	9

The detailed account on the description of the provenances/seed zones is given in Albæk (1993). Seeds were collected from selected mother trees that were at least 100 m apart. Seedlings were raised in Metema District Agricultural Office tree nursery, and were planted in a randomized complete block design (RCBD), (four replications with a total of 25 trees per plot with 4 m x 4 m spacing). The spacing between plots and blocks was 4 and 5 m, respectively. Survival count was conducted one year after planting while root collar diameter (RCD) and height of the inner 3 m x 3 m plants were measured at fourth year after planting. Analysis of Variance (ANOVA) was computed for the mean values of the observed variables using SPSS. Furthermore, Statgraphics Centurion XVI.I was used for visualization of the data.

Result and Discussion

Gum yield from natural stands

The present study indicated the possibility of gum production from natural stands of *A. senegal*. Table 2 presents the proportions of trees that yield gum according to the tapping position and season. The proportion of trees that produced gum was the highest (66.7%) in the tapping conducted in October at branches of the trees. However, the lowest records were observed from trees tapped in October and November at low stem position. Overall the October and the branch tapping resulted in the highest gum producing tree proportions, 45.1% and 48.9%, respectively. This could be due to the physiology of the species that at the beginning of October the trees start to shade their leaves and translocate the carbohydrates from their leaves to branches.

Table 2. Proportion of trees that yield gum in response to tapping (data from 2001 tapping and yield)

Season	Position				
	Branch	High stem	Mid stem	Low stem	Mean
October	66.7	60.0	53.5	0.0	45.1
November	53.3	21.3	26.7	0.0	25.3
December	26.7	46.7	13.3	6.6	23.3
Mean	48.9	42.7	31.2	2.2	31.2

Effect of tapping season and tapping position on gum yield

Gum yield from natural stands of *A. senegal* was highly variable with tapping seasons and tapping positions and among trees that were tapped in similar season and position. Considering only those trees that produce gum, the maximum yield was 368 g/tree in the first two pickings while the lowest was 1 g/tree. The mean yield of gum per tree in the first two pickings was significantly different among the tapping position levels ($p=0.01$) but was not significant between tapping season levels ($P=0.63$) (Table 3). No interaction effect was also observed between tapping season and position on gum yield ($P=0.252$).

Table 3. ANOVA of mean gum yield of *A. senegal* trees

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	468.439[a]	9	52.049	3.505	.003
Intercept	1051.267	1	1051.267	70.797	.000
Month	13.882	2	6.941	.467	.630
Position	201.146	3	67.049	4.515	.009
Month * Position	83.368	4	20.842	1.404	.252
Error	549.413	37	14.849		
Total	3941.960	47			
Corrected Total	1017.852	46			

a. R Squared = .460 (Adjusted R Squared = .329)

Figure 1 presents the mean gum yield of the first two pickings at the three levels of tapping seasons. Tapping in October yielded higher gum (96.46 ± 20 g/tree) in the first two pickings. The lowest yield was recorded in December that is 45 ± 18 g/tree. The yield was higher than the yield from natural stands (36 g/tree/two pickings) and farm gardens (55 g/tree/two pickings) reported from the Sudan (Ballal *et al.,* 2005). It was comparable with experimental natural stands (98 g/tree/two pickings) but lower than the yield from experimental plantations (123 g/tree/two pickings). There was significant difference in the mean yield between October and December. The results clearly indicated that the best yield could be obtained by tapping the trees at the beginning of October. Thus, October is appropriate season to commence tapping for better yield.

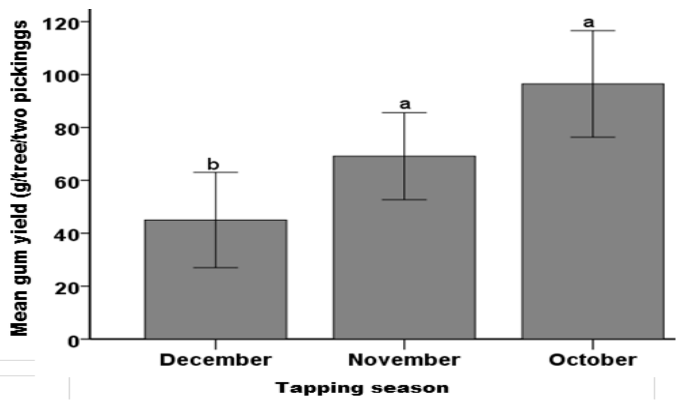

Figure 1. Gum yield of different tapping seasons.

The mean separation indicated the yield from mid stem tapping position was significantly different from other tapping positions (Figure. 2). The mid stem position gave a mean yield of 154.8±29 g/tree which is higher than the highest yield (110.7 g/tree) reported in Sudan from the first two pickings (Adam and Fadl, 2011).

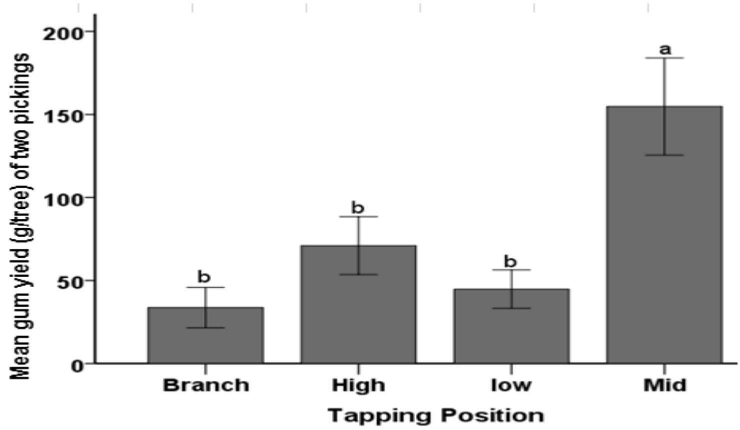

Figure 2. Gum yield at different tapping positions.

The first and second pick of gum yield was highly correlated to the total yield and taken as a direct indicator of total annual yield per tree (Ballal, 2002; Ballal *et al.,* 2005). This yield can be used to predict total yield per tree in a given year and the coming years by taking into account the temperature, rainfall, tapping season and intensity. Our study considered the gum yield of the first two pickings only due to the location of the research area and logistic availability. Overall, the gum yield in the first two pickings of the present study was comparable with that reported in the Sudan by Ballal (2002) and Ballal *et al.* (2005) and Adam and Fadl (2011).

Survival, RCD and Height growth of *A. senegal* provenances

Survival, diameter and height growth are important indicators of adaptability and performance evaluation in the evaluation of species and provenances (Ræbild, 2003). Although, the primary purpose of provenance evaluation was for gum yield, the early performance of provenances in terms of survival, root collar diameter, and height was evaluated to select the best performing provenance for establishment of plantations in the Northwest lowlands of Amhara.

Survival

The survival one year after planting varied between 61% and 100%, the lowest survival being in the Central Rift valley (LAN 10-1) provenance and the highest from Abderafi (AD 11-3) provenance (Figure 3). High variability in survival was observed between blocks in the LAN 10-1, WAF3-1 and NB9 provenances. The analysis of variance showed that there was a statistically significant difference (*p=0.03*) between provenances. This could be explained by the genetic and environmental variability of the species (Ross, 1979).

Table4. ANOVA for survival percentage of provenances of *A. senegal*..

Source	Type III Sum of Squares	DF	Mean Square	F	P-Value
Provenance	4054.33	5	810.867	3.22	0.0298
Within groups	4527.5	18	251.528		
Total (Corr.)	8581.83	23			

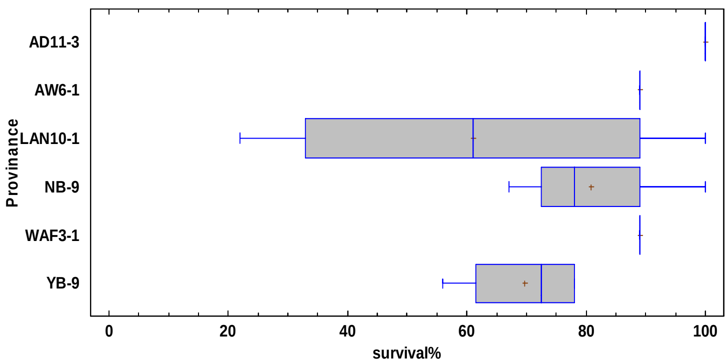

Figure 4. Within provenance variation of survival

Height and root collar diameter (RCD)

The height and growth of root collar diameter in the present experiment was highly variable. Statistically significant difference was observed between provenances both in height (*p=0.0)* and root collar diameter (*P=0.01)* growth (Table 6). The overall mean height growth was 113±5 cm, while the mean root collar diameter was 28±1mm at the age of forth year. The highest height (148±11 cm) and RCD (38±11 mm) growth was observed from the Abderafi provenance (AD11-3) followed by the Central Rift Valley (LAN10-1). On the other hand, the lowest height (80±5 cm) and RCD (17±0.8 mm) growth was recorded from Yabelo (YB9) provenance (Table 5). The result on the performance of the species in the trial site indicates its suitability for promotion of small and large-scale plantation.

Research on patterns of natural variation in commercially and adaptively important traits is essential in order to develop tree improvement and plantation development for native species of commercial importance. This is particularly urgent for *A. senegal* for commercial production of gum arabic with international demand. There has been little systematic research on provenance variation in growth and survival of *A.senegal* species in Ethiopia. Initiatives of *A. senegal* plantation establishment for gum arabic production tend to look germplasm from abroad (eg. Sudan) since the local varieties are considered as of inferior quality for gum production. However, the present study revealed that *A. senegal* trees fairly respond to tapping and could yield comparable gum arabic. The observed survival and growth may qualify Abderafi AD11-3 provenance as a potential seed source for establishment of *A. senegal* plantations in North- Western lowlands of Amhara Region with similar climatic and ecological condition with Metema area.

Table 5. Mean height and root collar diameter growth over provenances of *Acacia. senegal*

	Provenance	*Mean*	SD	Std. Error of Mean	*CV%*
Mean height (cm)	AD11-3	148	62.3	10.7	42.1%
	AW6-1	107	43.6	7.8	40.5%
	LAN10-1	134	86.1	20.3	63.9%
	NB9	92	42.8	9.4	46.3%
	WAF3-1	104	50.1	9.0	47.8%
	YB9	80	22.7	5.1	28.1%
	Total	**113.6**	**57.9**	**4.7**	**50.9%**
Mean RCD(mm)	AD11-3	38	10.6	1.8	28.4%
	AW6-1	28	9.0	1.6	32.7%
	LAN10-1	32	20.6	4.8	63.8%
	NB9	27	10.2	2.2	38.3%
	WAF3-1	22	8.6	1.5	39.4%
	YB9	17	3.5	0.8	20.3%
	Total	**28**	**12.7**	**1.0**	**45.8%**

Table 6. ANOVA of height and RCD of provenances of *Acacia senegal.*

	Source	Sum of squares	DF	MS	F	Sig.
Height	Between Provenance	266323.973	5	53264.795	16.646	.000
	Within provenance	623957.969	195	3199.784		
	Total	890281.942	200			
RCD	Between Provenance	2434.052	5	486.810	3.016	.012
	Within provenance	31470.764	195	161.389		
	Total	33904.816	200			

Conclusions and Recommendations

Gum yield was highly variable among trees and found to be affected by tapping season and tapping position. The yield recorded in our study was comparable to that reported in the Sudan, the leading producer of gum arabic. Thus, tapping the trees at appropriate season and at appropriate position can enhance the production of gum arabic from natural stands of *A. senegal*. Generally, we recommend tapping of branches starting from October when the trees start shading their leaves. Although the yield per tree from mid stem position was higher, we recommend tapping the branches in order to minimize damages on trees and to maximize yield by tapping many branches.

Although, there are many other factors that are speculated to affect gum yield per tree in natural stands of *A. senegal*, the present study considered only two of them: season/time to commence tapping and the position where tapping should be done. Moreover, the yield from only the first two pickings was considered in this study although gum can be collected up to 10-12 pickings at an interval of 15 days after the first tapping without refreshing the wound. Thus, we recommend further research undertakings that consider more variables in all the pickings. This can be properly conducted in permanent trial plots so as to integrate other ecological studies related to the species.

Survival, diameter and height growth were highly variable both between and within provenances of the species. This could clearly explain the genetic and environmental variability of the species. Best survival, diameter and height growth were recorded from Abderafi AD11-3 provenance. Thus, this provenance is recommended for the area surrounding the trial site.

Finally, promoting gum arabic tapping and production techniques and development of plantations of the species in pure stand as well as incorporation with the dryland farming systems will expect to contribute to rural livelihood improvement, the national economy and associated environmental benefits, including land rehabilitation. These benefits are in line with the current economic development strategy, Agricultural Development Lid Industry (ADLI) and export based production system and import substitution, of the country. In the face of growing demand of gum arabic in the international market, investing in the development and promotion of appropriate tapping techniques of the vast natural stands of *A. senegal* in the country and establishment of commercial plantation will be highly rewarding.

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Tapping and Carbon Balance of the Frankincense Tree

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Introduction

Trees of tropical dry woodlands face strong seasonality in rainfall and thus in water stress. In such water stressed environments, trees face trade-offs between carbon uptake and water loss (Cowan and Farquhar, 1977; Collatz *et al*., 1991). When trees close their stomata to avoid water loss with increasing drought in air and soil (Zweifel *et al*., 2007), this comes at the cost of low carbon gain (Tuzet *et al*., 2003; McDowell *et al*., 2008).

Most of our current knowledge of tropical systems comes from rain forests, where the discussion is dominated by pioneer-shade tolerance concepts (Markesteijn *et al*., 2007), or canopy-understory concepts (Poorter, 2009; Niinemets, 1997). Other studies are more on tropical savannas (e.g. Sarmiento *et al*., 1985; Myers *et al*., 1997 *et al*., Eamus *et al*., 1999; Goldstein *et al*., 2008; Bucci *et al*., 2008). There is relative scarcity of knowledge on African dry woodland species; especially in their carbon gain as related to climate.

In this study, we investigated the carbon balance of *B. papyrifera*, the frankincense-producing tree in contrasting environments. The frankincense producing *Boswellia* trees dominate large areas of dry woodlands in eastern and central Africa and elsewhere, where resin is often tapped by local communities for local or international markets (Ogbazghi *et al.,* 2006, Tadesse *et al.,* 2007; Mertens *et al.,* 2009). Tapping creates a carbon sink that is at the cost of growth sinks, including vegetative growth and reproduction (Cannell and Dewar 1994; Rijkers *et al.* 2006; Silpi *et al.* 2006; Chantuma *et al.,* 2009).

For such resin producing trees, the annual whole-crown carbon gain depends on a number of functional plant traits, environmental conditions, and tapping intensity. Functional traits that affect crown carbon gain include leaf photosynthetic rates, total leaf area and average leaf lifespan (Kikuzawa and Leichowicz 2006; Selaya and Anten, 2010). For two contrasting populations we determined: (1) the effect of tapping intensity on functional traits and crown carbon gain; (2) the possible effects of contrasting site conditions on crown carbon gain; (3) how frankincense tapping influences the total non-structural carbohydrate content of trees, and (4) the impact of tapping on annual and seasonal carbohydrate allocation pattern to different sinks. Because the resin is rich in carbon (Hamm *et al.,* 2005, Mertens *et al.,* 2009), tapping is expected to drain carbon reserves limiting the carbon availability for leaf formation. We expect a higher tapping intensity to reduce crown leaf area and hence canopy carbon gain. We also expect that trees in the drier high altitude area, with a shorter rainy season, will be restricted in the crown carbon gain by the limited leaf lifespan, and thus be more affected by tapping compared to low altitude trees. We also expect trees to face "exhaustion" of storage carbon after competing carbon sinks during the long dry season and possible "re-fill" when canopies are in full leaf during the short wet season. We discussed leaf and canopy traits that enable *Boswellia* to survive in contrasting sites and compare their response to light scenarios.

Materials and Methods

Species and study areas

The species *Boswellia papyrifera* (of the family Burseraceae) occurs in dry woodlands of the Sudano-Sahelian region of Nigeria, Chad, Sudan, Central African Republic, Uganda, Ethiopia, Somalia, and Eriterea (Lovett and Friis 1996; Ogbazghi et al., 2006). *Boswellia* is classified as a low altitude species occupying an altitudinal range of 537-1800 m (Birhane et al. 2010, Ogbazghi et al. 2006). In Ethiopia, the species is indigenous and occurs in the northern, western and central parts of the country (Tengnas and Azene 2007, Tadesse *et al*., 2007). The species is intensively exploited for the frankincense than before, putting an extra pressure on the declining populations (Rijkers *et al*., 2006; Ogbazghi *et al*., 2006; Peter et al. 2011).

B. papyrifera is a deciduous tree up to 13 m tall. The tree is monoecious and has compound leaves that contain 9-20 pinnately veined leaflets supported by petioles. It grows mainly in tropical dry woodlands with the centre of geographic distribution in the Horn of Africa (Lovett and Friis, 1996). The species is mainly found on rocky steep slopes and hilly areas with the roots not going deep but extending sideways on shallow surface soils (Ogbazghi *et al*., 2006). Flowering and fruiting occurs during the dry leafless season. Upon wounding, the tree produces a water-soluble resin (frankincense) with distinctive fragrance.

Adult trees of *B. papyrifera* were selected for this comparative field study at Metema, an area at relatively low altitude (810-990 m) and Abergelle at relatively high altitude (1400-1650 m). The Abergelle site is drier and is characterized by rainfall that is more erratic and a shorter wet season than Metema. We marked experimental trees of similar diameter (20$\pm$3 cm DBH) in Abergelle and Metema areas. The sample sizes differ due to the *a priori* assumption of different productivity levels between plots in Metema. The marked naturally grown *Boswellia* trees were randomly subjected to different tapping treatments (0, 6 and 12) during the dry season (as practiced locally). Wood, bark and root (including wood and bark) samples were collected from trees to determine storage carbon at the end of the wet season and end of the dry season. All samples were analyzed for total non-structural carbohydrates (TNC). TNC is defined here as the sum of free sugars (sucrose, glucose and fructose) and starch. TNC commonly covers more than 90% of mobile carbon in plants (Hoch *et al*., 2002; Hoch *et al*., 2003) and other carbohydrates were not included in this analysis because they contribute little (Hoch *et al*., 2003). Total non-structural carbohydrates (TNC) were determined by high-performance liquid chromatography (HPLC).

Gas exchange was measured on five leaves of the experimental trees. We estimated annual canopy assimilation from these experimental trees using leaf gas exchange data during the growing season for two years. Subsequently, we estimated the wet season annual carbon gain (dry season is leafless) by integrating the daily photosynthetic rates to total leaf area and leaf lifespan. Annual crown carbon gain is referred here as the gross primary productivity (GPP).

We distinguish between major sinks that are part of the net primary production (NPP), the respiration costs (R), or storage. The net primary production consist of foliage production ($NPP_{foliage}$), wood production (NPP_{wood}), root production (NPP_{root}), frankincense, and fruits production costs. The respiration costs include the maintenance respiration costs of foliage ($R_{foliage}$), wood (R_{wood}) and roots (R_{root}). The third category is allocation to storage a carbohydrate (TNC), which does not only act as a potential sink of the acquired carbon but also as a potential carbon source for other sinks. The overall carbon budget model is presented.

Data analysis

A general linear model with univariate analysis and Tukey *post-hoc* multiple comparisons was used to test the effect of tapping intensity on plant traits driving annual carbon gain. The analysis was done by including the interaction between sites and tapping intensity as a fixed factor. The relationship between photosynthetic rates or crown leaf area with crown carbon gain and frankincense yield was tested by linear regression models. Data was analyzed using SPSS (PASW 17.0 for Windows statistical software package).

Results

Light response curves

The light response curves showed that leaves exhibited the typical asymptotic trend in photosynthesis with increasing light levels. Mean A_{max} (Metema ~ 15 and Abergelle ~ 22 µmolm^{-2}s^{-1}) was however significantly lower (P = 0.01) and achieved at lower light levels for Metema (~1200 PPFD) than for Abergelle (~1600 PPFD). In line with this, leaf nitrogen content tended to be lower at Metema, but this trend was not significant (T-test, P = 0.09, N = 21 for Abergelle and N = 57 for Metema). Dark respiration (R_d), light compensation point (Γ), quantum yield (ϕ) and curvature (θ) did not differ significantly between the two areas (Figure 1).

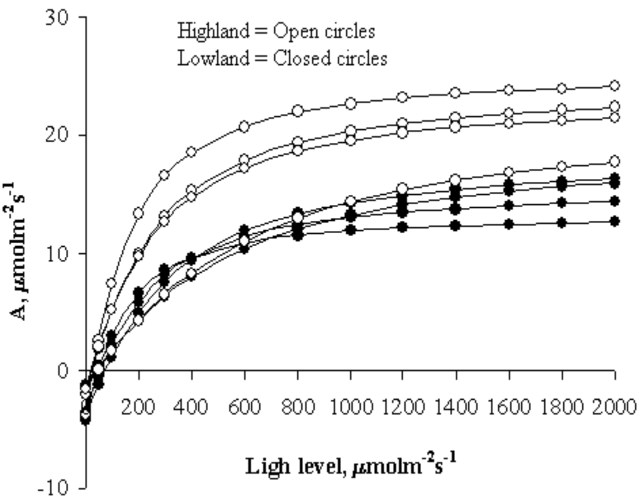

Figure 1. Light response curves in the two sites.

PHENOLOGY.– Leafing and senescence started earlier in the low altitude than in the high altitude (Figure. 2). Nevertheless, the estimated effective crown leaf lifespan was 81 days in the low altitude and only 69 days in the high altitude. In both sites, leaf bud burst already started before the actual onset of the first rains. Flower and fruit production occurred during the leafless dry period, but sites differed in their timing (Figure 2). Fruit bud initiation started early during the dry season shortly after leaf shedding in the low altitude, whereas it occurred at the end of the dry season in the high altitude.

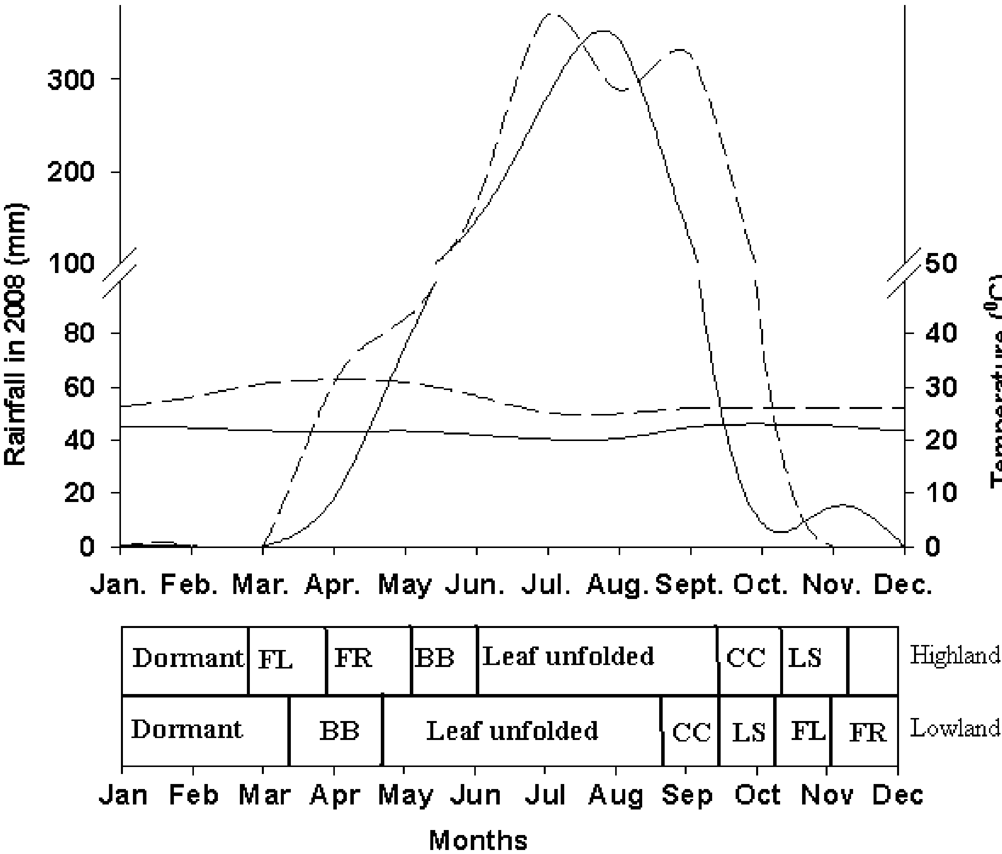

Figure 2. Variable phenophases in the frankincense tree in the high and low altitude areas.

Tapping effects on leaf area and carbon gain

Tapping reduced crown leaf area in the low altitude, but not in the high altitude. Because of the reduction in crown leaf area, estimated annual crown assimilation was lower for heavily tapped trees in the low altitude (Figure 3). The estimated average annual crown assimilation of trees was higher in the high altitude (1081 $molCO_2/yr \pm$ 118) than in the low altitude (776 $molCO_2/yr$ $\pm$ 72. A higher light interception together with high photosynthetic capacity resulted in higher photosynthetic rates in the high altitude compared to the low altitude (Figure 3). With similar average crown leaf area between the two sites, the shorter crown leaf lifespan of trees in the high altitude apparently was more than compensated by their higher photosynthetic rates (0.35 $molCO_2/m^2/d$ versus 0.23 $molCO_2/m^2/d$, Figure. 3B, D, E). Neither crown assimilation nor crown leaf area leads to higher frankincense yield in both sites.

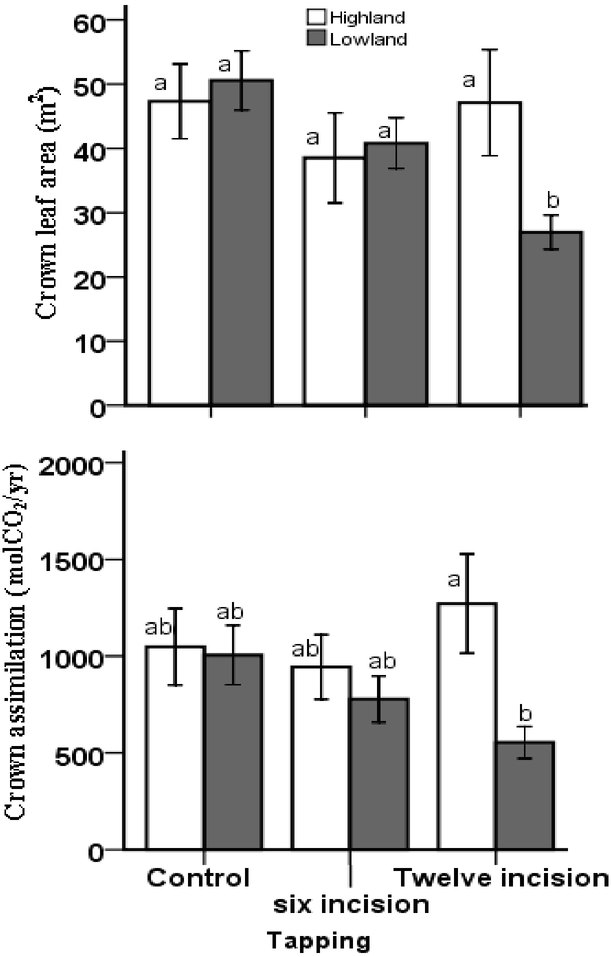

Figure 3. The impact of tapping intensity on crown leaf area and carbon gain

TNC concentrations

The mean total non–structural carbohydrates (TNC) concentration for Boswellia trees was 2.96 mg/g_{dw}. The high altitude and the low altitude populations did not differ significantly in TNC concentrations. About 62% of TNC in the low altitude and 70% in the high altitude consisted of starch and the remaining is soluble sugars. Both concentrations and pool sizes were lower in tapped than untapped trees (Figure 4). TNC has generally lower values at the end of the dry season and refilling during the wet season. In terms of whole-tree pools, the stem contained the highest reserve pools, while roots and bark had equal amounts.

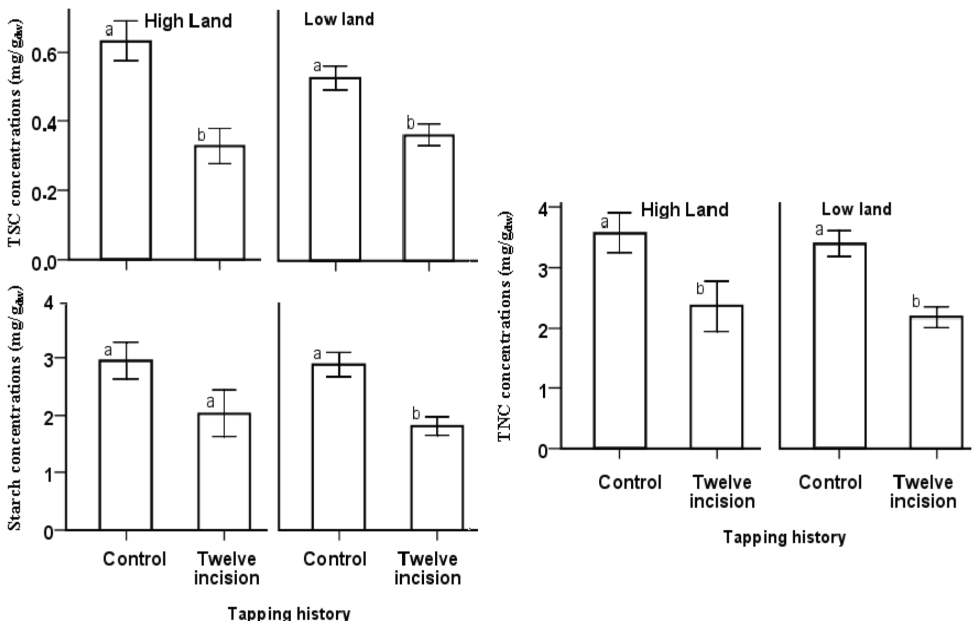

Figure 4. The impact of tapping on storage carbohydrate

Carbohydrate allocation pattern

For both sites, most carbon was used for maintenance respiration (8.8 kg in the high altitude site and 12.1 kg in the low altitude site). Annual crown net primary production is the second biggest sink (1 kg and 2 kg) and the frankincense production the third biggest carbon-consuming sink (4%), (Figure 5). Wood and fruit production were the least carbon demanding sinks in Boswellia trees.

Intensive tapping reduced the amount of carbon allocated to foliage ($NPP_{foliage}$, $R_{foliage}$) and reproductive sinks (NPP_{reprod}) in the low altitude (Figure 5), but this was not observed for the high altitude.

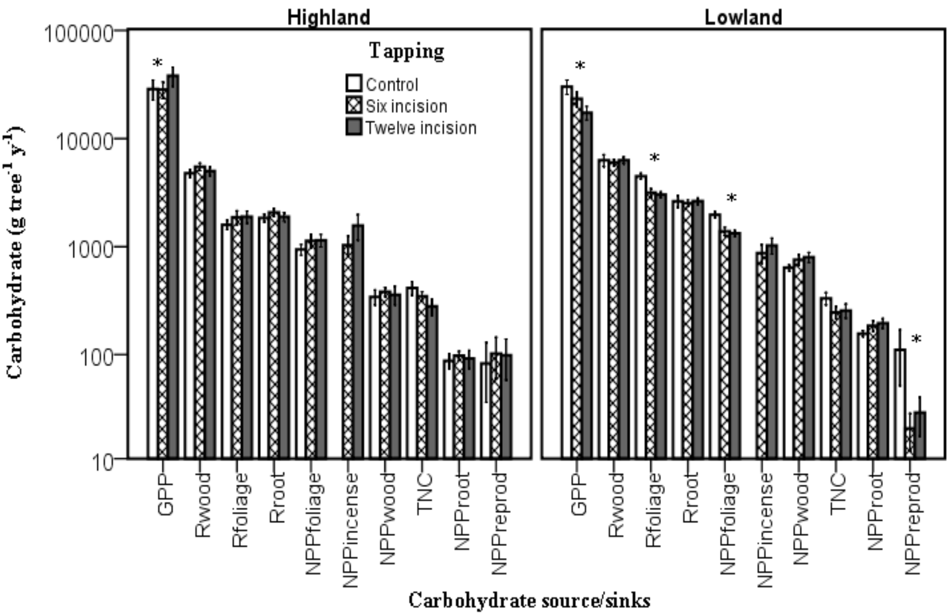

Figure 5. Allocation of carbohydrates to the different sinks in relation to tapping

Discussion

We expected trees in the drier highland area, with a shorter rainy season, to be restricted in crown carbon gain as a result of limited crown leaf lifespan (Suárez, 2010), and also to be more affected by tapping. This was clearly not the case. Despite their shorter leaf lifespan, trees of the drier highland attained substantially higher annual crown assimilation. This difference was the product of the greater light availability (less cloud cover) and the larger photosynthetic capacities of trees at the highland site. These two factors more than compensated for the shorter leaf lifespan at this site. On the other hand, the shortcomings of reduced leaf lifespan in the highland tend to be compensated by the ability of trees to exploit resources (*e.g.* light, nutrient, moisture) at a rapid rate (Kushwaha *et al.*, 2010) thus achieving higher photosynthetic rate and coping the major challenge of the short availability of growing conditions (rainy season) in dry tropical woodlands.

Total leaf area and carbon gain of lowland trees were negatively affected by intensive tapping. This suggests a trade-off between tapping and leaf formation: the carbohydrate used for resin production was at the cost of the carbohydrate to be invested in leaf area, comparable to the resin production to reproduction trade-off (Rijkers *et al*., 2006) and rubber production to growth trade-off (Silpi *et al*., 2006; Chantuma *et al*., 2009).

TNC (reserve carbohydrates)

Despite differences in leaf phenology, carbon gain, microclimate conditions, and altitude, TNC concentrations were similar between the two areas. The higher annual carbon gain at high altitude thus is not reflected as a higher storage carbohydrate concentration. In our study, resin production during the dry season reduced the concentration of storage carbohydrates in Boswellia trees. Hence, stored carbohydrate is used as a coping mechanism to an increased carbon sink thru tapping.

TNC levels in the frankincense tree indeed decreased during the leafless dry season. This is in agreement with results from other studies (Steele *et al*., 1984; Hoch *et al*., 2003; Silpi *et al*., 2007; Chantuma *et al*., 2009).

The total of the estimated annual carbon sinks to the different components were 38-68% of the annual carbon gain in both study sites but these sinks did not include sinks for root exudates, export for mycorrhiza, resin stock increment, volatile organic compound emission and herbivory (e.g. insect on leaf and bark). However, *Boswellia* trees establish mycorrhizal association (Birhane *et al*., 2010) and the consumption of carbon by the fungal symbiont can be stronger (Corrêa *et al*., 2011). Mycorrhization can consume up to 20% of the total fixed carbon (Smith and Read 2008). Therefore, assuming 20% mycorrhization cost, the total carbon cost can reach 68-88% of the GPP. Overall, we hypothesized that tapping will reduce carbohydrate allocation to all the other competing sinks. For example, we expect carbohydrate depletion by tapping to negatively affect fruit/seed setting (cf. Stephenson 1981; Ho 1988, Rijkers *et al*., 2006). In general, this prediction is partially supported in our study, because tapping traded-off with fruit production in the lowland only. Despite the fact that tapping is out of phase with foliage development, tapping also reduced the amount of carbohydrates allocated to foliage growth ($NPP_{foliage}$) and respiration ($R_{foliage}$) in the lowland. This may have a negative effect for the next season survival and growth.

Trees in the highland have higher annual carbon gain (the gross primary production, GPP) that may help to buffer the impact of tapping. Alternatively, following the arguments based on growth differentiation balance hypothesis (Herms and Mattson, 1992; Kleczewski *et al*., 2010), it might be that the highland trees are constrained by other resource limitations (e.g. moisture) such that carbohydrates become available for frankincense production.

Increasing GPP, however, does not lead to an increase in carbon supply to most, but not all sinks. Our expectation is thus only partially supported. Only partitioning to foliage production indeed increased with carbohydrate resource availability in the plant system. Remarkably, other carbon sinks such as frankincense production, were not affected by carbon gain. This suggests that for example trees produce similar amount of resin, irrespective of the total carbon available. This means that trees with low carbon gain (little leaf area) might suffer sooner from carbon starvation.

Conclusions

Heavy tapping negatively affected leaf area production and annual crown assimilation in the lowland. In the highland, trees are less affected by tapping due to better light conditions and larger photosynthetic capacities that enable a greater annual carbon gain. Thus, the combined effect of higher photosynthetic rate and shorter leaf lifespans resulted in more carbon gain than the combined effect of long leaf lifespan and lower photosynthetic rate. This study confirmed that tapped trees contain less reserve carbon than control trees. Therefore, tapping indeed drains the carbon storage of the frankincense tree.

Reduced TNC concentrations after tapping in all tissues and the seasonal dynamics of carbohydrate reserves appear relevant parameters to cautiously evaluate the long-term sustainability of tapping *Boswellia* trees in the dry woodlands systems. The carbohydrate consumption by tapping *Boswellia* trees remains a critical drain of up to 4% of the tree carbon budget. Although tapping competes with growth and reproductive sinks, the extent of competition for carbohydrates between frankincense production and other costs was site specific. Trees produce similar amount of resin, irrespective of the total carbon available. This means that trees with low carbon gain (little leaf area) might suffer sooner from carbon starvation by tapping and is advisable to stop tapping smaller trees.

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Stand Status and Yield Economics of *Acacia Senegal* Wild At Abderafi North Western Ethiopia

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Introduction

Dryland forests in Africa represent an important resource base for livelihoods and economic development (Suderland and Ndoye, 2004; Shackleton *et al*., 2008; Paumgarten and Shackleton, 2009). If managed wisely they have the capacity to provide a perpetual stream of income and subsistence products, while supporting other economic activities through ecological services and functions (Mulugeta *et al*., 2004; Chikamai *et al*., 2009).

The *Combretum–Terminalia* and *Acacia–Commiphora* deciduous woodlands belong to the category of dry forests, and form the largest vegetation cover in the Horn of Africa and the Sudano-Sahelian zone (Friis, 1992). These forests mainly are composed of various species of *Acacia, Boswellia,* and *Commiphora* that are known to produce commercial plant gums and resins (Mulugeta and Demel, 2003). Moreover, the wood and non-wood products from these species play a significant role in the livelihood of many people in the dryland regions of Africa.

In Ethiopia, dry forest is the largest remaining forest type that currently covers 55 million ha (WBISPP, 2004). These forests are rich in *Acacia*, *Boswellia* and *Commiphora* species (Mulugeta, 2005; Abiyu *et al*., 2010; Abeje, 2011), that provide the important export commodities such as gum arabic, frankincense and myrrh (FAO, 1995, Mulugeta, 2005; Mulugeta and Habtemariam, 2010; Abiyu *et al*., 2010; Abeje, 2011). These forests, however, are suffering from severe degradation due to anthropogenic pressures (Mulugeta *et al*., 2007; Eshete *et al*., 2005; Asefaw, 2006; Abiyu *et al*., 2010). They are continuously shrinking by the expansion of agricultural lands and human settlement (Mulugeta *et al*., 2007; Tatek, 2008).

Acacia senegal is one of the promising multipurpose tree species in arid and semi-arid areas of Ethiopia, which have various socio-economic and ecological benefits. The natural stands of *A.senegal* found in the broad and small leaved deciduous woodlands of the country; West Tigray, Amhara, Benshangul, Shewa, Afar plane and Borena zone of Oromia (Azene *et al.,* 1993; Fitchel and Admassu, 1994; Haile, 2012). The survival of the species in such areas makes it a key stone species that can provide plant cover and plays an important role in desertification control. Apart from these, the species is highly valued for gum arabic production (Mulugeta *et al,*, 2004) in which the gum is exudates from trunks, branches and twigs. However, in recent years, the forests that possessed *A.senegal* tree species, in the dryland part of Ethiopia are subject to increasing pressure (Mulugeta *et al.*, 2007; Tatek, 2008).

Rapid population growth from natural birth as well as migration, clearance for cropland expansion, overgrazing, and intensification of gum-resin extraction are some of the major factors driving deforestation and degradation of dry forests in Ethiopia (Abeje *et al*., 2005; Asefaw, 2006; Mulugeta *et al*., 2007; Abiyu *et al*., 2010). Unfortunately, in spite of its wide distribution and the increasing pressure, adequate knowledge on the status of its population is crucial for a sustainable management of this resource.

The objectives of this study were thus to describe the population structure and quantify the density of *A.senegal*; analyze the natural regeneration status of the species*;* and assess the possibility of commercial harvesting of gum arabic from the natural stand.

Materials and Methods

The study area

The study was conducted in north Gondar zone of Abderafi wereda. It lies within an altitudinal range of 950 to 1100 m above sea level. The mean annual rainfall is 885 mm, and the annual mean temperature is 27.8 ºC. It has a unimodal rainfall and most of the rainfall is received during the months of July and August. The soils are predominantly black, and some soils have vertic properties. Seasonal water logging, especially during the heavy rainfall months, is also high. The vegetation zone of the study area is categorized under the *Combretum–Terminalia* or Broad-Leaved Deciduous Woodland (Abeje, 2002; Ogbazghi *et al*., 2006). Geographically it is situated between latitude 13.73 ° N and longitude 36.45°E.

Data collection and analysis

A reconnaissance survey was made across the woodland in the study area, in order to obtain a contemplation of the status of the resource base in the study area. Three sites were selected to investigate the resource status of *A.senegal*. Thirty-two sample plots of size 20 x 20 m were laid at regular intervals along parallel transects with smaller sample plots of size 5 x 5 m nested in the center of each plot for regeneration count. The transect line and the plots were laid with 500 m and 300 m intervals, respectively. Diameters at breast height (DBH) of individual trees were taken for those individual trees with the heights of 1.5 m or more using diameter tape. For individuals with a height of less than 1.5 m, their basal diameters were measured using caliper (Abeje *et al*., 2005). In the regeneration plots, the numbers of *A.senegal* seedlings encountered were counted. Then, the status of *A.senegal* stands was examined based on the population structure, density of the species, and regeneration status.

The population structure of the species is depicted using frequency histogram of diameter classes and number of regeneration (Abeje *et al*., 2005). For the purpose, all individuals of the species encountered in the quadrats were arbitrarily grouped by 4 cm diameter classes (0 – 4 cm, 4 – 8 cm, 8 – 12 cm, 12 – 16 cm, 16 - 20…32 – 36 cm, and >36 cm). Frequency was obtained by counting the number of plots in which the species was recorded (Kent and Coker, 1994; Tadesse, 2003). The density was calculated by the number of individuals of a species per unit of area (Abeje *et al*., 2005) using equation 1.

$$\text{Density/ha} = \left(\sum_{i=1}^{n} d/n\right) * 25 \ldots\ldots\ldots\ldots \text{equation1}$$

Where, d = is stem number/plot and n = number of plots.

Gum yield (kg) per hectare and year was calculated by multiplying the mean *A.senegal* stem density per hectare calculated above with the mean yield (kg/tree/year) (equation 2). The latter was obtained from previous studies for the same species (Duke, 1983).

$$Gum\ yield/ha \cdot yr = \left(\sum_{i=1}^{n} d/n * 25\right) * y(kg/tree \cdot year) \ldots\ldots\ldots equation2$$

Where, d = is stem density/plot, n= is number of plots and y =is gum yield per tree and year.

Results and Discussion

Species composition and tree density

Nine woody tree species were identified in association with *A. senegal* in the woodland of the study area. List of the woody tree species in the stand is given in Table 1. Compared to similar vegetation types in Ethiopia (Dry lowland vegetation), the species composition of the study area is more or less comparable with previously studied dryland woodlands. For instance Mekuria *et al.,* 1999 and Getachew, 1999 reported only six woody tree species in the upper riftvalley woodlands vegetation and in addition to this Kindeya, 2003 also reported 13 woody tree species in the woodlands of Tigray.

The woodland in general was dominated by *A.senegal* tree species in terms of tree density followed by *Acacia seyal* (Table 1). *A.senegal* had the highest density of 356 individual stems ha^{-1} thus accounting for 70.70% of the stem composition of the study woodland in terms of tree density. This number is higher as compared to some similar vegetation types in Ethiopia. For example, Mulugeta *et al.*, 2001 indicated that 59.6 ha^{-1} individual of *A.senegal* trees found in the Liben zone of Somali region.

Generally the density of *A.senegal* tree species in the study woodland is an indication of the availability of more individuals of *A.senegal* trees for gum production though the optimum density that would ensure sustainable supply of gum is not known. The densities of *A.senegal* and associated trees species were presented in Table 1.

Table 1. Frequency, Density (Individuals ha^{-1}) and Percentage of tree species in the study woodland

Species name	Frequency	Density (ha^{-1})	Percent (%)
Acacia Senegal	456	356.25	70.70
Acacia seyal	65	50.78	10.08
Diorostachys ginerea	38	29.69	5.89
Combretum adenogonium	11	8.59	1.71
Combretum spp	26	20.31	4.03
Grewia ferruginea	9	7.03	1.40
Balanytes aegyptica	19	14.84	2.95
Stereospermum kunthianum	1	0.78	0.16
Dalbergia melanoxylon	22	17.19	3.41

The average density of *A.senegal* trees with diameter ≥ 4 cm (number of mature individuals) is 211 stems ha^{-1} thus accounting 58.61% of *A.senegal* stems of the study woodland (Table 2). This number is comparable with the harvestable size (matured trees reached for harvesting of gum arabic) of *A.senegal* trees in the central rift valley vegetation which is ranging from 12 – 209 ha^{-1} with the inclusion of individuals at diameter class of greater than or equal to 2 cm (Dagne, 2006). However, in our estimation we did not include those individuals with the diameter ≥ 2 cm. Yet, the stand of the *A.senegal* in the study woodland has sufficient number of trees for launching commercial harvesting of gum arabic in the study area. Thus, it is encouraging to start the gum arabic business in the study area.

Table 2. Frequency, Density (Individuals ha^{-1}) and Percentage of *A.senegal* tree species in different diameter classes of the study woodland

DBH Class (cm)	Frequency	Density (ha^{-1})	Percent (%)
2 – 5	213	166.41	46.6
6-10	154	120.32	33.7
11-15	66	51.56	14.4
16-20	18	14.06	3.9
>21	6	4.69	1.3

Population structure

Information on population structure of a tree species indicates the history of the past disturbance to that species and the environment and hence, used to forecast the future trend of the population of that particular species (Peters, 1996). The result of the present study indicated that the diameter class distribution of the whole vegetation of the study woodland exhibits a stable and growing population structure (Figure 2) where the majority of the species had the highest number of individuals at lower diameter with gradual decrease towards the higher diameter classes. This suggests that good reproduction and recruitment potential of the veg; etation (Kindeya, 2003Feyera, 2006). However, this pattern does not depict the general trends of the recruitment processes of a given species. Analysis of population structures of individual species could provide more realistic and specific information for conservation measures.

Fortunately, the population structure of *A.senegal* was similar with that of the structure of the whole vegetation (Figure 3). The existence of an inverted J-shaped structure for *A.senegal* tree species in the study woodland representing higher number of individuals in the lower diameter class and gradual decrease in the frequency of higher diameter class exhibiting a stable and growing population structure which is suggesting good reproduction and recruitment potential of *A.senegal* in the study area (Kindeya, 2003; Feyera, 2006).

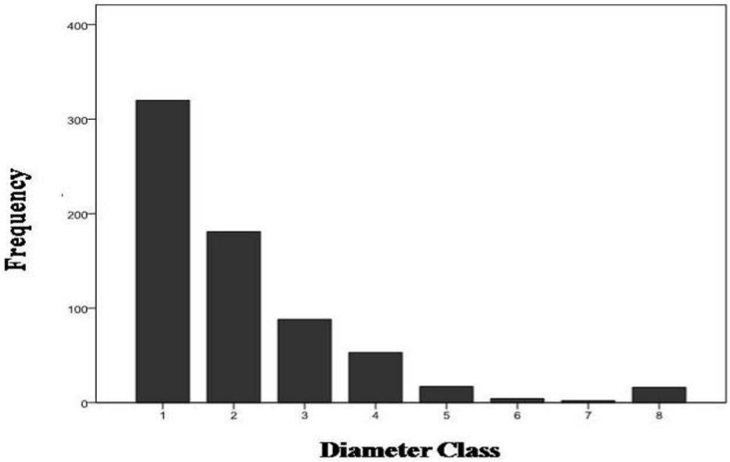

Figure 2. Population structure of the whole vegetation of the study woodland at Abderafi

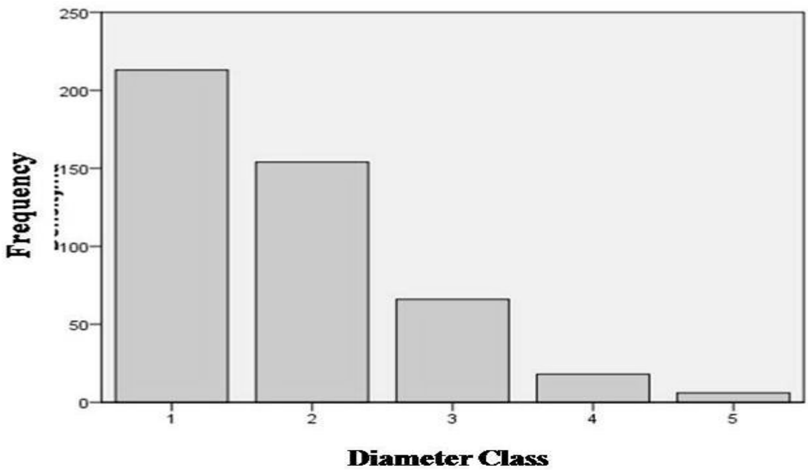

Figure 3. Population structure of *A.senegal* in the study woodland of Abderafi

Regeneration status

According to Mekuria *et al*.(1999(and Kindeya (2003), composition and density of seedlings would indicate the status of the regeneration of a given population of trees. In this study, out of the nine tree species only four were found to be in a good regeneration status (Table 3). Of these species, *A.senegal* showed good regeneration contributing more than 54.48% to the total density of regeneration followed by *A.seyal* (19.84%), *Combretum* spp (8.17%) and *Balanites aegyptica* (5.84%). The good regeneration status of *A.senegal* in the study woodland might be the abundant seed production and soil seed bank formation of the species (Demel, 1996) or the thorny nature of the species which help the seedlings to escape the browsing effects of the cattle (Mekuria *et al.,* 1999 and Getachew, 1999). However, the result of regeneration in general indicated the sustainability and possibilities of future commercialization of gum arabic from the natural stand of *A.senegal* trees in the study areas.

Table 3. Frequency, density (ha^{-1}) and percentage representation of seedlings of tree species in the woodland

Species	Frequency	Seedling density (ha^{-1})	Percent
Acacia Senegal	180	140	54.48
Acacia seyal	65	51	19.84
Diorostachys ginerea	8	12	4.67
Grewia ferruginea	9	7	2.73
Balanytes aegyptica	19	15	5.84
Dalbergia melanoxylon	1	1	0.39
Combretum adenogonium	11	9	3.51
Combretum spp	26	21	8.17
Stereospermum kunthianum	1	1	0.39

Potential gum yields and economics

As there are no information on gum yield of *A.senegal* from the natural stand, gum yield (kg) per hectare and year was estimated by multiplying the mean stem density of *A.senegal* per hectare with the mean yield (kg/tree/year) as the yield was obtained from previous studies (Duke, 1983). According to Duke (1983), annual yields from young *A.senegal* trees may range from 188 to 2856 g/tree (avgerage 0.9 kg), from older trees, 379 to 6754 g/tree (average 2 kg).

The mean *A.senegal* stem density was 211 stems/ha (Table 2) with a mean gum production of 0.9 to 2 kg/tree/year, the mean gum arabic yield expected was about 190 to 422K g/ha/year. This estimation included only those individuals of *A.senegal* trees with the diameter ≥ 4 cm. Such good yield suggested that the possibilities of future commercialization and the sustainable production of gum arabic from the natural stand of *A.senegal* trees in the study areas. Accordingly, the price for gum arabic is $US 5000 per ton (FAO, 1995), about about \$US 950- 2110 ha^{-1} $year^{-1}$ could be obtained from *A.senegal* stand of the study woodland.

Conclusions

From the preset study it is understood that the vegetation in Abderafi Wereda shown to have high potential for gum arabic production from the natural stand of *A.senegal*. The result indicated that the population status of *A.senegal* is found to have higher density and good regeneration suggesting stable and healthy population. Moreover, the diameter distribution of individual trees of *A.senegal* indicated most of them are matured enough to be tapped signifying there is a possibility to start commercial harvesting of gum arabic if appropriate management activities are applied. Thus, this study could be taken as baseline information for planning future economic development of this valuable species in the study area through considering the multiple uses of the species.

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Population Structure, Tree Morphology, and Development of *Boswellia papyrifera* in Tekeze River Basin, Tigray, Northern Ethiopia

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Introduction

Boswellia papyrifera (Del.) Hochst is a key dryland and deciduous multipurpose tree species native to Ethiopia and widely known commercially as bitter frankincense and belongs to the family *Burseraceae*. Natural gum and resin producing trees, mainly the *Boswellia* species are found in the drier low lying arid to semi-arid lands in Ethiopia at altitudes varying from 200–1800 m a.s.l, temperature range of 21-25^{0}c and with rainfall of less than 900 mm per annum (Azene *et al.,* 1993; Ogbazghi , 2001). They are dominantly found in the Tigray, Afar, Amhara, Beneshangul-Gumuz, Gambella, Oromiya, and Ethiopian Somali National Regional States. Despite the actual and potential economic and ecological significance of *B. papyrifera*, its area coverage is reported by different authors to be dwindling from time to time (Kindeya, 2003).

Therefore, this study tried to fill the gap of knowledge particularly on the status of *B. papyrifera* and its population structure, regeneration, tree morphology and development and how various characteristics of environmental variables affect the species' population structure, morphology growth, and development of individual trees in areas like Tekeze River Basin. This was conducted through field inventory at Tekeze River Basin specifically to determine and investigate its current population structure, regeneration, tree morphology and development; to determine effect of altitude, slope and soil properties on its population structure, tree morphology and development; and to recommend management intervention to maintain the existing vegetative cover.

Materials and Methods

Study area description

The study was conducted in the dry forests of north western and western zones of Tigray Regional State, where *B. papyrifera* naturally exist. Plains and rugged topography characterize the relief of their agroecologies, which includes hot to warm semi-arid low lands (SA_1), hot to warm sub-moist low lands and river gorges (SM_{1-4}) and tepid to cool sub-moist mid-highlands (SM_{2-5}), mountainous and plateau (TARI, 2002). Large areas of the *Boswellia* species in weredas/administrative districts of northwestern and western Tigray are localized at the border edge of Tekeze River and to some few inaccessible pocket areas of the aforementioned areas. The sub-agro ecology category of the Tekeze river basin is hot to warm sub-moist low lands and gorge (SM_{1-4}). It is characterized by low altitude with high temperature and erratic but torrential rainfall (TARI, 2002). The basin area comprises 29 weredas of Tigray and 20 Weredas of Amhara Regional State. It is entirely located in Northern Ethiopia with different agro-climates and varying area coverage (Tekeze River Basin Integrated Master Plan Project, 1997). The presence of different agro-climates together with existence of different soil resources and socio-economic conditions contributes to the existence of varying farming systems throughout the basin.

Considering the pushing of *B. papyrifera* growing areas towards river basins and the agroecology and climate suitability of Tekeze river basin to enrich and maintain the existing stands of the study species, Tekeze river basin was selected as the actual site for the analysis of exiting threats and its overall challenges and opportunities. Based on secondary data and prior reconnaissance survey, three study sites located in Tekeze river basin from three weredas (namely, *Tselemti*, *Asgede-Tsimbla* and *Kafta-Humera*) were selected. Selection of study sites were based on the occurrence of relatively intact *Boswellia* stands; altitude range; accessibility; and current management condition of *B. papyrifera* stands.

The distribution of the study sites were, one from *Asgede-Tsimbla* (designated or coded as Site I), one from *Tselemti* (designated or coded as Site II) and one from *Kafta-Humera* (designated or coded as Site III). A total of 39 plots (1.56 ha), 13 plots (0.52 ha) from each study site were taken for the actual study.

Site I

This is located at *Addi-Agew* locality ('*Kushet*'), *Mizan* peasant association (PA), along the Tekeze river basin in *Asgede-Tsimbla* wereda in Northwestern zone of Tigray. The altitude and slope range of Site I, in which the study plots lied were from 850 to 1300 m and 4% to 82%, respectively. Site I has an aspect of south west, which is faced towards the Bridge of Tekeze River (on the way from *Shire* to *Gonder*). Free grazing, charcoal production with no tapping and crop cultivation are the main management interventions or land use activities practiced in this specific study locality.

Site II

This is located at *Newi* locality ('*Kushet*'), *Mai-Anbessa* Peasant association (PA) along the Tekeze rive basin in *Tselemti* wereda in northwestern zone of Tigray. The altitude and slope range of Site II, in which the study plots lied were from 850 to 1150 m a.s.l and 22% to 70%, respectively. Site II has an aspect of North West, which is faced towards the Bridge of Tekeze River (on the way from *Shire* to *Gonder*) and bounded by another river called *Frafra* from southwest. Unlike study site I, free grazing, charcoal production, tapping and crop cultivation are main management interventions or land use activities practiced.

Site III

This is located at *Tekeze* locality ('*Kushet*'), *Addi-Goshu* PA along the Tekeze rive basin in *Kafta-Humera* wereda, from western Tigray. The altitude and slope range of Site III in which the study plots lied were from 750 to 1000 m a.s.l and 5 to 55%, respectively. Site III has an aspect of north east, which is faced towards the Bridge of Tekeze River (on the way from *Humera* to *Sheraro*). In contrast, to the other two study sites, relatively this study site was free of interferences or encroachments from free grazing, charcoal production, tapping, and crop cultivation.

Sampling procedures and plant measurements

Three and six parallel vertical lines spaced by 300 m, were laid at Site I and II, and Site III, respectively, due to site and altitude range variations. Selected sites were represented the entire range of altitude, in which the species grows within the valley. In each of these sites, the upper and lower altitude limits were determined, subsequently hypothetical line was drawn perpendicular to the contour lines delineating the lowest and highest altitude limits. The whole altitude range covered in each study site was divided into narrower altitude intervals or vertical distances of 100 m (Ogbazghi *et al.,* 2006). Within the defined altitude intervals, sample plots measuring 20 x 20 m was placed parallel to the contour lines. Moreover, a 3 x 3 m small plot at each corner and in the center of the big plot (20 x 20 m m) was taken for natural regeneration assessment (Kindeya, 2003). In each sample plot all *Boswellia* plants were inventoried and measured. Plant height, stem diameter, crown depth, and crown diameter were determined for each *Boswellia* individual.

Data collection and analysis

In each sample plot, within the entire altitude of the river basin of the three selected sites, all *Boswellia* individuals was counted and recorded. The height and DBH of individuals were measured using suunto clinometers and diameter tape, respectively. Crown depth and crown diameter of each *Boswellia* tree was also taken from each plot. Topographic features (Altitude, slope, and aspect), land use type and other management interventions were recorded. Altitude and inclination of the terrain (slope in degrees) was determined using an altimeter and suunto clinometers, respectively. Geographic location of each study plot was also recorded using GPS.

To determine the population structure of *B. papyrifera,* size frequency distribution diagrams have been made for each study site by grouping plants into nine stem diameter size classes (1 = <1 cm, 2 = 1-2, 3 = 2-4, 4 = 4-8, 5 = 8-16, 6 = 16-24, 7 = 24-32, 8 = 32-40, and 9 ≥ 40 cm). Similarly eight height (1= <1 m, 2= 1-2, 3= 2-4, 4= 4-6, 5= 6-8, 6= 8-10, 7= 10-12 and 8= >12 m), crown diameter (1≤1 m, 2= 1-2, 3= 2-3, 4= 3-4, 5= 4-5, 6= 5-6, 7= 6-7 and 8 ≥7 m) and crown depth (1≤1 m, 2= 1-2, 3= 2-3, 4= 3-4, 5= 4-5, 6= 5-6, 7= 6-7 and 8 ≥7 m) size classes were used to determine the population structure and morphology of the frankincense tree (Abeje *et al*., 2005; Ogbazghi *et al*., 2006).

Linear regression analysis was used to describe the relationship between the various morphological traits and altitude and slope. In this case, per sample plot, the tree with the highest value for stem diameter, tree height, crown depth and crown diameter was taken (Ogbazghi *et al*., 2006). In each study site, Pearson's correlation was used to describe the relationship between stem diameter and the other morphological treats (crown diameter, crown depth, height) of the study species (Kindeya *et al.,* 2004; Ogbazghi *et al*., 2006).

Results

Population structure of Boswellia papyrifera in Tekeze river basin

The numbers of sample plots were equal in each study site. The structure, tree morphology, and development of *B. papyrifera* was determined and computed based on the number of individuals recorded in each study plot located at an altitude and slope ranges of 850-1250 m a.s.l. and 4–82%, respectively along Tekeze River Basin.

Stand diameter and height structure and distribution of B. Papyrifera

As indicated in Figure 1, the size class interval (SCI) 16-24 cm DBH had the highest number of individuals at site I (58 individuals, about 49.6 % of the population) and site III (113 individuals, about 55% of the population) followed by the SCI of 24-32 cm DBH in site I (28 individuals, about 24% of the population) and 8-16 cm DBH in site III (51 individuals about 25%). In contrast, the SCI of 24-32 cm DBH were found to have the highest (30 individuals, about 40% of its population) followed by SCI 16-24 cm DBH (27 individuals, about 34% of its population) in site II. The medium size trees (16-24 cm DBH) were most abundant with total of 198 individuals of which 58, 27 and 113 were found in site I, II and III, respectively. Among the three study areas, the highest abundance of individuals were found in size class intervals of 8-32 cm DBH in site III (196 individuals, about 69% of the population) followed by site II (111 individuals about 95% of the population) both sites having the same size class interval of DBH (Figure 1a, b)

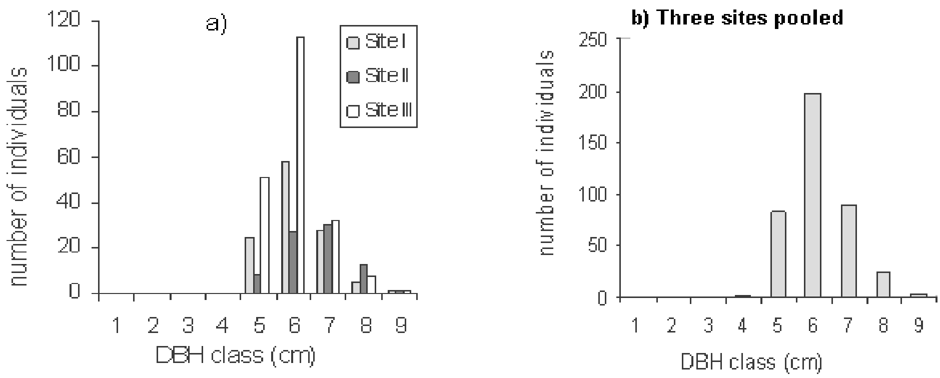


Figure 2. Stem diameter size distribution of *B. papyrifera* in three sites (a) and all sites pooled (b) located at Tekeze River Basin, Northern Ethiopia.

Where: 1= ≤ 1 cm, 2= 1-2 cm, 3= 2 – 4 cm, 4= 4 – 8 cm, 5= 8 – 16 cm, 6= 16 – 24 cm, 7= 24 – 32 cm, 8= 32 – 40 cm and 9 ≥40 cm.

The height (Figures. 2, a , b) class distribution of *B. papyrifera* in all study sites gave an empty record of individuals for the first two classes (ranged from 0-2 m). In contrast, the middle-sized trees (6-8 m) were most abundant with 169 individuals (about 42% of the total population) of which 50 (42.7% of the population), 32 (40.5% of the population) and 87 (42.4% of the population) were found in site I, II and III, respectively.

Among the other size class intervals, 8-10 m height were revealed higher number of individuals both in site I (24 individuals, 20.5% of the population) and site II (27 individuals, 34% of the population), unlike to site III in which higher number of trees (45 trees, 22% of the population) were recorded from size class interval of 4-6 m.

The population structure of *B.papyrifera* in all study sites show a consistent size class, most likely a bell shaped distribution of height and skewed structure of diameter classes with no individuals in the lowest 2 to 3 class intervals and progressively increasing and reach the highest number of individuals at 16-24 cm DBH and 6-8 m height class.

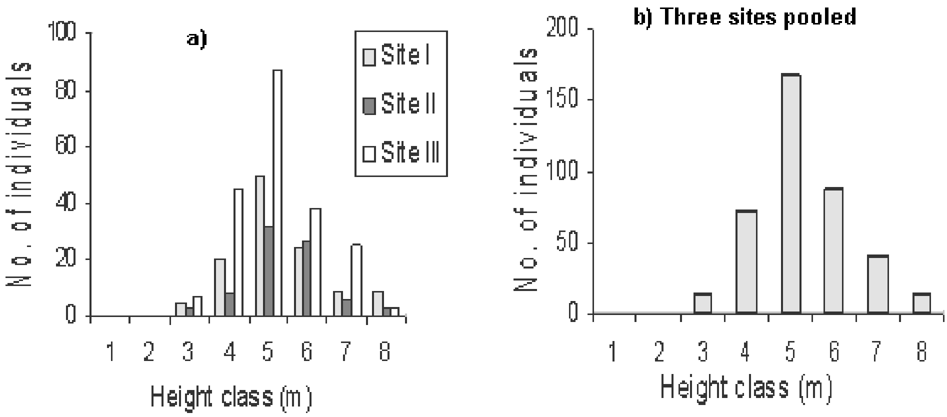


Figure 3. Tree height size distributions of *B. papyrifera* in three sites (a) and all sites pooled (b) located at Tekeze River Basin, Northern Ethiopia.

Where: 1≤ 1 m, 2= 1-2 m, 3= 2-4 m, 4=4-6 m, 5= 6-8 m, 6= 8-10 m, 7= 10-12m and 8 ≥ 12 m.

Stand crown diameter and depth structure and distribution

A considerable number of individuals were recorded in all crown diameter classes in site I and III, unlike site II, which had no record of individuals from the narrowest crown diameter classes ranged from 0–2 meter (Figure. 3 a). As indicated in Figure. 3 a, at site I, II and III, the highest record of individuals were found from different crown diameter size class distribution. Of this, 5-6 m in site I, 4-5 m in site II and 3-4 m in site III were revealed highest record of individuals. The highest records were 27 (23% of the population), 21 (27% of the population) and 77 (49% of the population) individuals in site I, II and III, respectively.

On the other hand, three crown diameter classes (≤ 1 m, 6-7 m and >7 m) were found as the lowest record of individuals at site III. More or less, a similar trend of crown diameter distribution was observed, when individuals of all study sites pooled together (Figure. 3b), that exhibited a sort of bi-modal distribution with few individuals at the lowest and highest (>7 m) classes progressively increasing in number of individuals up to the next consecutive classes and attains its maximum number of individuals in size class 3-4 m and gradually decreasing there after (Figure. 3b). Crown diameter class interval of 3-4 m were revealed most abundant with a total of 112 trees of which 21 were found in site I, 14 in site II and 77 in site III.

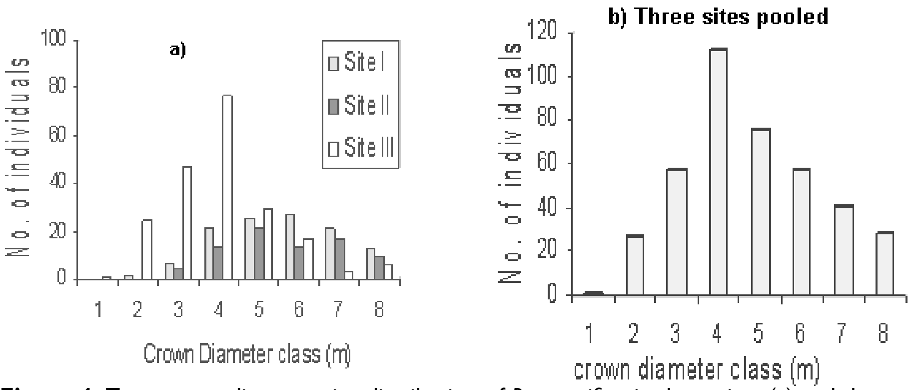


Figure 4. Tree crown diameter size distribution of *B. papyrifera* in three sites (a) and three sites pooled (b) located at Tekeze River Basin, Northern Ethiopia.

Where: 1 ≤ 1 m, 2= 1-2 m, 3= 2 -3 m, 4=3 – 4 m, 5= 4 -5 m, 6= 5 -6 m, 7= 6 -7m and 8≥7 m.

Figure 4a and b shows the size class interval 3 - 4 m crown depth had the highest number of individuals at site I (24 individuals, 21% of the population.) and 4 - 5 m crown depth at site III (22 individuals, 28 % of the population). At site III both size class 2 - 3 and 3-4 crown depth revealed an equal and highest number of individuals (80 individuals, 39% of the population pooled from the two classes), followed by 1-2 m (38 individuals, 19% of the population). Crown depth distribution of all plants (401) of the three sites with size class of 1-5 m were revealed most abundant with a total of 260, (about 65% of the total trees) of which 74 (63% of the population) were found in site I, 47 (60% of the population) in site II and 139 (about 68% of the population) in site III. In general the crown diameter and depth distribution in all the study areas show that there is a consistent size class distribution (Figure. 3b and 4b) trends with few individuals in the lowest two classes followed by the highest number of individuals in the next consecutive classes (2-5 m) and gradually decreasing there after for crown diameter distributions (Figure. 3b) and a sharp decline followed by progressive increase and another sharp decline to wards the highest upper classes for crown depth distribution (Figure. 4b).

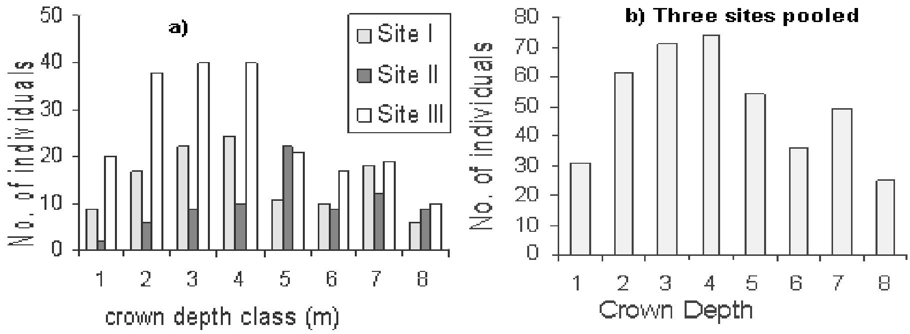


Figure 5. Tree crown depth size distribution of *B. papyrifera* in three sites (a) and all sites pooled (b) located at Tekeze River Basin, Northern Ethiopia.

Where: 1 ≤1 m, 2= 1- 2 m, 3= 2 – 3 m, 4=3 – 4 m , 5= 4 – 5 m, 6= 5 – 6 m, 7= 6 – 7 m and 8 ≥7 m.

Tree morphology and development of B. papyrifera at Tekeze river basin

Values of crown diameter were found variable (R^2 = 0.129) and significantly ($P < 0.05$) affected by altitude (Figure. 5c) compared to the other morphological traits (maximum DBH, height and crown depth) of the study species which were not significantly affected by altitude and revealed low values of coefficients of determination (R^2) ranged between 0.00001 for crown depth and 0.02 for DBH. This shows that, the relationship between altitude and morphological traits of *Boswellia* trees are very weak compared to crown diameter. The maximum DBH of the three sites ranged between 20 cm and 45 cm (Figure. 5a). Similarly, tree height was ranged between 6.8 m and 13.5 m (Figure. 5b).

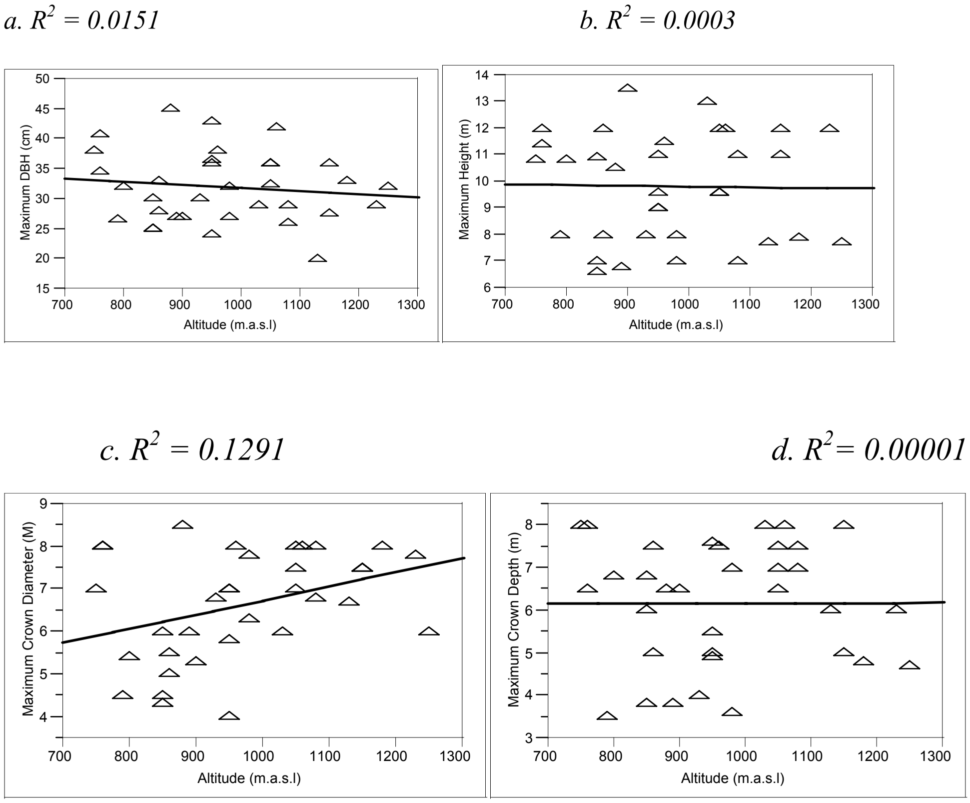


Figure 6. The relationship between altitude and maximum DBH (a), maximum height (b), maximum crown diameter (c) and maximum crown depth (d). Each symbol represents a sample plot of which in each case a single tree was selected having the highest value for each of the four morphological traits. R^2 is indicated.

Based on the results of regression analysis, the relationship between slope and the other four morphological traits of *Boswellia* trees was very week with 0.0259, 0.0158, 0.0062 and 0.0147 coefficients of determination for DBH, height, crown diameter and crown depth, respectively (Figure. 6a, b, c, d). The regression analysis was also revealed that slope has no any significant effect on response of morphological traits of *Boswellia* trees in the three study areas.

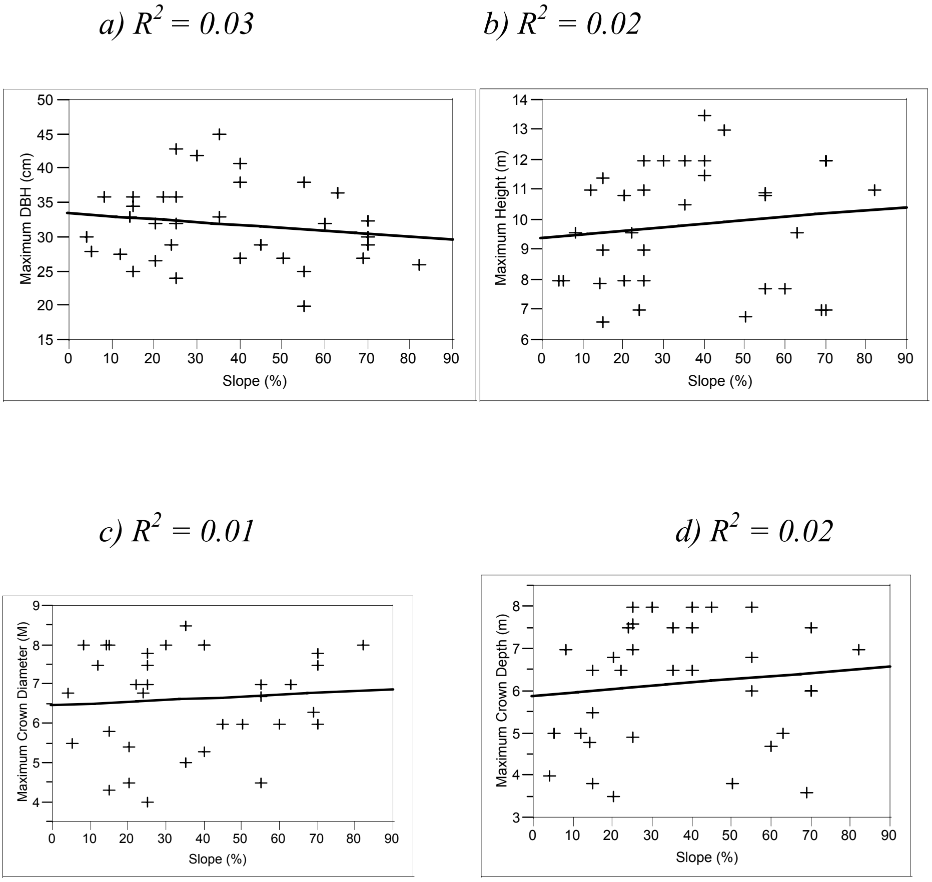
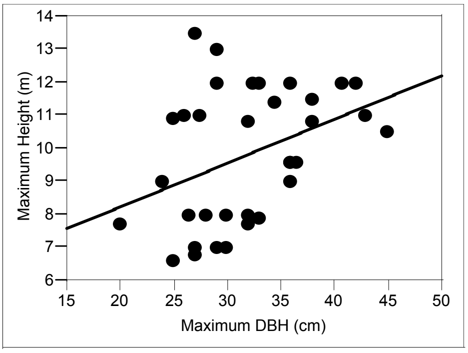


Figure 7. The relationship between slope and maximum DBH (a), maximum height (b), maximum crown diameter (c) and maximum crown depth (d). Each symbol represents a sample plot of which in each case a single tree was selected having the highest value for each of the four morphological traits. R^2 is indicated.

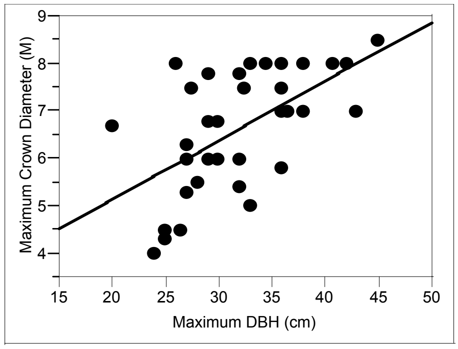
In the present study, the linear relationship of stem diameter with crown diameter, crown depth, and height was analyzed for each study site and all sites pooled as indicated in Figure 7 and Table 1. The regression analysis models that describing the relationship between stem diameter at 1.3 m in height and tree height, crown diameter and crown depth indicated that the changes in plant height (a), crown diameter (b) and crown depth (c) were influenced significantly ($P < 0.05$) by stem diameter.

As indicated in Figure. 7, more or less there is a linear relationship between tree height, crown diameter and crown depth and stem diameter. For all the dependent variables pooled for all sites, the explained variation of the model ranged between 15% and 33% (Table 1). The model predicts better to crown diameter than both tree height and crown depth. Tree development in terms of crown diameter, crown depth and tree height with increasing stem diameter was similar in all study sites.

a) $R^2 = 0.15$



b) $R^2 = 0.33$



c) $R^2 = 0.25$

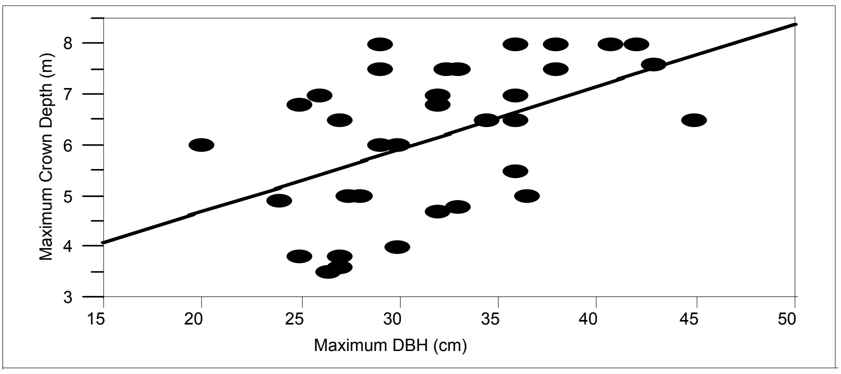


Figure 8. The changes in plant height (a), crown diameter (b) and crown depth (c) in relation to DBH of *B. papyrifera* trees. Each symbol represents a sample plot of which in each case a single tree was selected having the highest value for each of the morphological traits. R^2 is indicated. All curves were significant at $P < 0.05$.

When the relationship between stem diameter and crown diameter, of *B. papyrifera* in three sites was compared, the regression coefficients of determination (R^2) in site I, II and III has revealed 0.08, 0.21 and 0.73, respectively. Similarly, the relationship between stem diameter and crown depth, of *B. papyrifera* was significant ($P < 0.05$) with 57% of coefficients of determination in site III, unlike site I and site II that revealed 0.7% and 11%, respectively. The linear relationship between stem diameter and tree height in study site I and III were not significant; where as study site II was significant ($P < 0.05$) and revealed R^2 values of 75 % (Table 1).

Crown diameter, crown depth, and height of *B. papyrifera* tree were positively correlated with stem diameter. Among the morphological traits crown diameter and crown depth were relatively moderately correlated with stem diameter (Pearson's correlation coefficient of 0.58 and 0.50, respectively). In contrast, height of *Boswellia* trees were weakly correlated with stem diameter compared to crown diameter and depth as computed from all study sites (Pearson's correlation coefficient of 0.4).

Table 1. The relationship between maximum DBH and maximum height, crown diameter and crown depth of *B. papyrifera* in the three study sites and all sites pooled at Tekeze river basin in Northern Ethiopia.

Study Site	Linear Regression Equation	R^2
I	Ht = 0.0439(DBH) + 8.3912	0.0166
	CDi = 0.0417(DBH) + 5.7995	0.0759
	CDe = 0.0189(DBH) + 5.1389	0.0071
II	Ht = 0.3599(DBH) – 3.1734	0.7459*
	CDi = 0.0666(DBH) + 4.9206	0.2127
	CDe = 0.0669(DBH) + 4.6112	0.1049
III	Ht = 0.2118(DBH) + 3.6165	0.2703
	CDi = 0.2133(DBH) – 0.7871	0.7262*
	CDe = 0.2267(DBH) – 0.8892	0.5667*
All sites pooled	Ht = 0.1313(DBH) + 5.6250	0.1457*
	CDi = 0.1241(DBH) + 2.6673	0.3322*
	CDe = 0.1231(DBH) + 2.2369	0.2519*

*Note: Diameter at 1.3 m height in cm (DBH); Crown Diameter in meter (CDi); Crown Depth in meter (CDe); tree Height in meter (Ht) and Coefficient of determination (R^2), * Significant at 5% probability level.*

Discussion

Population structure of *B.papyrifera* per study area and all areas pooled shows a constant size class with relatively a bell shaped distribution for height and highly skewed for diameter classes' distribution. Similarly, crown diameter and depth (when individuals of all study areas pooled) shows more or less a bell shaped distribution with some deflection at the upper class of crown depth. It was surprising that, not even a single naturally regenerated seedling or sapling of *B. papyrifera* was found in all study areas. Similarly, there were no *Boswellia* trees in the lowest class (≤ 8 cm DBH, ≤ 2 m in height) in all study areas.

According to Silver town J.W. and Doust, J.L. (1993), tree species with population structures skewed to an inverted “J” or “L-shaped” distribution (i.e. with many small individuals and a few larger ones) are considered to have favorable status for regeneration and hence stable population. In contrast, the present study clearly shows that *B. papyrifera* in all study areas has been getting a series problems of regeneration and disturbance. Therefore, *B.papyrifera* along the river valley has unstable and declining population. Of course, the present findings fits with the findings of Kindeya *et al.* (2003), Abeje *et al.* (2005) and Ogbazghi *et al.* (2006), who dealt on the same species. Crown diameter and depth size frequency distribution of all individuals of the three study sites, indicated that stands of *B.papyrifera* found along the entire altitude of the river valley have a medium crown diameter (ranged from 2-6 m) and crown depth (ranged from 1-5 m) size distributions. It is common to see similar size of crowns not only in the river valleys but also in other areas, where stands of *B. papyrifera* are naturally exist in north western and western areas of Tigray. In Eritrea, similar crown sizes have obtained and reported (Ogbazghi *et al*., 2006). The study shows that altitude and crown diameter have better relationship compared to stem diameter, tree height and crown depth.

The regression analysis models for all sites pooled describes that the relationship between stem diameters at 1.3 m in height, predicts better to crown diameter than both tree height and crown depth. Tree development in terms of crown diameter, crown depth and tree height with increasing stem diameter was similar in all study sites along the entire altitude range of the valley. Any management interventions that threats the crown of trees like *B. papyrifera* affects its productivity, as the tree crowns that bears leaves are the main sites for photosynthesis (Kindeya, 2003).

The coefficient of determination (R^2) values of the relationship between the stem diameter and crown diameter of *B. papyrifera* in closed areas are higher as compared to those in the free grazed areas (Kindeya, 2003). However, such correlation and linearity can be affected by external factors like browsing, fire, and branch cuttings. This study indicates that crown diameter, crown depth, and height of *B. papyrifera* trees were positively correlated with stem diameter.

Among the morphological traits, crown diameter gave better and higher correlation with stem diameter followed by crown depth (Pearson’s correlation coefficient of 0.58 and 0.50, respectively). The present finding fits with the findings of Kindeya (2003), who dealt on the same study species. He also indicated that all matured trees in natural forests show a strong correlation between diameter increment and crown sizes. Such correlation and linearity can be affected by external factors like browsing, fire and branch cutting, as shown in the present study, highly in site II and to some extent in site I of the river basin.

Conclusions

Based on the present study, the following main conclusions have made.

- The population structure of *B. papyrifera* shows a constant size frequency distribution with a bell-shaped structure of height and skewed structure of diameter classes. Therefore, this study clearly indicated that *B. papyrifera* along the Tekeze river basin has unstable and declining in population and has been getting a serious problem of natural regeneration and disturbance, as tree species with population structures skewed to an inverted "J" or "L-shaped" distribution are considered to have favorable status for regeneration and hence stable population;
- The long term performance of *Boswellia* trees and other associated woody species in the face of current land use in site II and site I remain uncertain;
- The results from the soil survey revealed that all study sites were dominated with low to medium organic matter content (1.2 – 4.5%), medium to high pH values (5.5 – 8), low to medium available phosphorus (1 – 8 p.p.m), and sandy loam to loam textural classification. This reflects that the soil conditions of Tekeze river basin in general have no significant variation and relatively low fertile, but still potential for the growth and development of *Boswellia* trees and other woody and deciduous species;
- Among the morphological traits, crown diameter has shown a linear and better relationship with altitude along the river basin compared to height and crown depth. The regression analysis of stem diameter also predicts better to crown diameter than both tree height and crown depth, when data of all sites pooled together.
- Local and regional polices and regulations should be formulated and implement through the participation and consultation of local individual farmers, cooperatives and/or unions and large scale investors or organization involved in the collection, processing and marketing of frankincense in order to protect and regulate the *Boswellia* stands grown at Tekeze river basin in particular and Tigray Region in general from external factors;
- Promotion and enrichment planting of *B. papyrifera* in *Boswellia* growing areas in general and in the river basin in particular should begin soon; and
- Further detailed studies should be conducted on the potential production of frankincense from *B. papyrifera* in Tekeze river basin and other watersheds of the Region.

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The Effects of Environmental Variables on Abundance and Distribution of *Boswellia papyrifera* and Associated Species in Tekeze River Basin

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Introduction

Boswellia papyrifera (Del.) Hochst is a lowland tree species growing to 12 m or more with a characteristic smooth and whitish to pale brown bark peeling off in large parchment flakes, found in *Acacia commiphera* woodlands, wooded grasslands and *combretum- terminallia* or broad leaved deciduous woodlands (Khan, 1972; Azene *et al.,* 1993). The genus *Boswellia* is composed of 20 or more species extending from Ivory Coast to India and south to north eastern Tanzania and northern Madagascar, but most numerous in north east tropical Africa (Vollesen *et al.*, 1989). Natural gum and resin producing trees, mainly the *Boswellia* species are found in the drier low lying arid to semi-arid lands in Ethiopia at altitudes varying from 200–1800 m a.s.l, temperature range of 21-25^{0}c and with rain fall of less than 900 mm per annum (Azene *et al.,* 1993; Ogbazghi, 2001). They are dominantly found in the Tigray, Afar, Amhara, Beneshangul-Gumuz, Gambella, Oromiya, and Ethiopian Somali National RegionalS. Its distribution in Africa includes Nigeria, Cameroon, Central Africa Republic, Chad, Ethiopia, Sudan, and northeastern Uganda (Azene *et al*., 1993; Chickmani, 2003). The center of geographical distribution, however, is located in the Horn of Africa, where more than 75% of *Boswellia* species are endemic to the area (Vollesen *et al.,* 1989).

Natural vegetation along gradients influences the types of soil eventually formed from a given parent material (Brady Nyle, 2002). The amount and vertical distribution of organic matter that accumulates in the upper part of the profile differs markedly between vegetation types along valley areas. Even though organic matter comprises only a small fraction of the mass of a typical soil, the influence of soil organic matter on soil properties and consequently on plant growth is far greater than the low percentage would indicate (Brady Nyle, 2002). In semiarid regions like Tigray, the lower effective rainfall on steeper slopes also results in less plant contribution to soil formation. For all these reasons, steep slopes prevent the formation of soil from getting very far ahead of soil destruction (Brady Nyle, 2002). Moreover, topography (mainly altitude and slope) often interacts with vegetation to influence soil formation.

The low land areas of the Regional State of Tigray, mainly its north western and western parts are highly recognized for their vast resource of frankincense extracted from *B. papyrifera* has not been systematically tapped and utilized (Tilahun, 1997; Kindeya *et al*., 2003). Though attempts have been made to address the subject at various occasions, much work remained to be done in order to understand the abundance and distribution and then effectively protect, enrich and utilize the resource in its natural stands particularly in river basins. Moreover, for conservation and proper management of the existing woody species in the semi-arid areas such as *Boswellia* stands, it is essential to understand how various environmental variables (soil, altitude, and slope) and current land use practices affect the abundance and distribution of *B. papyrifera* and other associated woody dryland species along river basins. There are several natural and anthropogenic factors that affect the abundance and distribution of *Boswellia* species in general and *B. papyrifera* in particular that urges research findings in Tekeze river basin.

Therefore, this study tried to fill the gap of knowledge particularly on the current status of its population abundance, regeneration, distribution and how various environmental variables affect the species' population abundance and distribution in areas where the species is existing naturally and areas potential for further domestication and production activities like Tekeze river basin. This was conducted through field inventory at Tekeze river basin specifically: 1. to determine abundance, regeneration status, occurrence, and distribution of the study and associated species to determine effect of altitude, slope and soil physiochemical properties on abundance/density and distribution of *B. papyrifera* and 3. to recommend possible management intervention to maintain the existing vegetative cover, expanding the size and lay out new technique by which the resource base is sustainably managed and utilized.

Materials and Methods

The study area

The study was conducted in the dry forests of north western and western zones of Tigray Regional State, where *B. papyrifera* naturally exist. Plains and rugged topography characterize the relief of their agroecologies, which includes hot to warm semi-arid low lands (SA_1), hot to warm sub-moist low lands and river gorges (SM_{1-4}) and tepid to cool sub-moist mid-highlands (SM_{2-}

$_5$), mountainous and plateau (TARI, 2002). Large areas of the *Boswellia* species in weredas/administrative districts of northwestern and western Tigray are localized at the border edge of Tekeze River and to some few inaccessible pocket areas of the aforementioned areas. The sub-agroecology category of the Tekeze river basin is hot to warm sub-moist low lands and gorge (SM_{1-4}). It is characterized by low altitude with high temperature and erratic but torrential rainfall (TARI, 2002). The presence of different agro-climates together with existence of different soil resources and socio-economic conditions contributes to the existence of varying farming systems throughout the basin. Considering the pushing of *B. papyrifera* growing areas towards river basins and the agroecology and climate suitability of Tekeze river basin to enrich and maintain the existing stands of the study species, Tekeze River Basin was selected as the actual site for the analysis of exiting threats and its overall challenges and opportunities. Based on secondary data and prior reconnaissance survey, three study sites located in Tekeze River Basin from three weredas namely *Tselemti*, *Asgede-Tsimbla,* and *Kafta-Humera* were selected. Selection of study sites were based on the occurrence of relatively intact *Boswellia* stands; altitude range; accessibility and current management condition of *B. papyrifera* stands. The distribution of the study sites were, one from *Asgede-Tsimbla* (designated or coded as Site I), one from *Tselemti* (designated or coded as Site II) and one from *Kafta-Humera* (designated or coded as Site III). A total of 39 plots (1.56 ha), 13 plots (0.52 ha) from each study site were taken for the actual study.

Site I

This is located at *Addi-Agew* locality ('*Kushet*'), *Mizan* peasant association (PA), along the Tekeze river basin in *Asgede-Tsimbla* wereda in Northwestern zone of Tigray. The altitude and slope range of Site I, in which the study plots lied were from 850 to 1300 m a.s.l and 4% to 82%, respectively. Site I has an aspect of south west, which is faced towards the Bridge of Tekeze River (on the way from *Shire* to *Gonder*). Free grazing, charcoal production with no tapping and crop cultivation are the main management intervention or land use activities practiced in this specific study locality.

Site II

This is located at *Newi* locality ('*Kushet*'), *Mai-Anbessa* Peasant Association (PA) along the Tekeze rive basin in *Tselemti* wereda in northwestern zone of Tigray. The altitude and slope range of Site II, in which the study plots lied were from 850 to 1150 m a.s.l and 22% to 70%, respectively. Site II has an aspect of North West, which is faced towards the Bridge of Tekeze River (on the way from *Shire* to *Gonder*) and bounded by another river called *Frafra* from southwest. Unlike study site I, free grazing, charcoal production, tapping and crop cultivation are main management interventions or land use activities practiced.

Site III

This is located at *Tekeze* locality ('*Kushet*'), *Addi-Goshu* PA along the Tekeze rive basin in *Kafta-Humera* wereda, from western Tigray. The altitude and slope range of Site III in which the study plots lied were from 750 to 1000 m a.s.l and 5 to 55%, respectively. Site III has an aspect of north east, which is faced towards the Bridge of Tekeze River (on the way from *Humera* to *Sheraro*). In contrast, to the other two study sites, relatively this study site was free of interferences or encroachments from free grazing, charcoal production, tapping and crop cultivation.

Sampling procedures and soil survey

Three and six parallel vertical lines spaced by 300 m, were laid at Site I and II, and Site III, respectively, due to site and altitude range variations. Selected sites were represented the entire range of altitude, in which the species grows with in the valley. In each of these sites, the upper and lower altitude limits were determined, subsequently hypothetical line was drawn perpendicular to the contour lines delineating the lowest and highest altitude limits. The whole altitude range covered in each study site was divided into narrower altitude intervals or vertical distances of 100 m (Ogbazghi *et al.,* 2006). Within the defined altitude intervals, sample plots measuring 20 x 20 m was placed parallel to the contour lines. Moreover, a 3 x 3 m small plot at each corner and in the center of the big plot (20 x 20 m) was taken for natural regeneration assessment (Kindeya, 2003). In each sample plot all *Boswellia* plants were counted and measured. The identities of other associated tree and shrub species were determined in the field and for those species that proved difficult to identify in the field, their local names were registered and identified in the national Herbarium in Addis Ababa, Ethiopia. To investigate the effect of soil properties as one of the environmental factors for the density and distribution of the study species at river basins and altitude gradients, in the center and in each of the four corners of each sample plot, soil sub-samples were collected from the upper 30 cm of the soil layer. Per plot, the soil samples were pooled and stored in polyethylene bags in order to reduce variability. The composite soil samples were divided into five equal parts, among which one was selected randomly as a working soil sample and analyzed in the laboratory for physical and chemical properties.

Data collection

In each sample plot, within the entire altitude of the river basin of the three selected sites, all *Boswellia* individuals, and other associated species were counted and recorded. Topographic features (Altitude, slope, aspect) and other management interventions were recorded in each study plot. Altitude and inclination of the terrain (slope in degrees) was determined using an altimeter and suunto clinometers, respectively. Geographic location of each study plot was also recorded using GPS. Necessary soil samples from each study plot were collected using auger, stored in polyethylene bags, and then analyzed at Mekelle Soil laboratory Research Center. Moreover, undisturbed soil samples were taken from each study plot using core sampler and bulk density determination was conducted.

Data analysis

Differences in abundance and distribution of *B. papyrifera* (number/ha) among sites, altitude, slope and soil factors were evaluated using linear regression analysis at different levels of significances (Kindeya *et al.,* 2004; Ogbazghi *et al*., 2006). In each study site, Pearson's correlation was used to describe the relationship between the abundance of *B. papyrifera* and the environmental factors (altitude, soil, and slope). A multiple linear regression analysis with forward selection procedure was used to evaluate the relative importance of the various environmental factors (Ogbazghi *et al*., 2006). Each independent variable was analyzed to investigate how each one affects the occurrence and abundance of the species. Soil samples were analyzed at Mekelle soil laboratory for chemical and physical properties (soil organic matter (OM), pH, Electrical conductivity (EC), texture, available soil phosphorus (P), exchangeable potassium (K), cation exchange capacity, and other relevant properties). Bulk density determination and appropriate drying, grinding and sieving were done at Shire soil laboratory. Analysis was conducted based on (Walkley-Black, 1934; Olsen *et al*., 1954; Jackson, 1958).

Results

Status of economically important woody species compared to Boswellia papyrifera

The floristic composition of woody and shrub species associated with *B. papyrifera* along the entire altitude range of the river was described in terms of presence (+) or absence (-). During field survey, 28 species were recorded in all study areas. Density and frequency of other important woody species (ranked in order of importance by the local communities and informants) compared to *B. papyrifera* in the three study areas was depicted in Figure 1. It was indicated that *B. papyrifera* had the highest density (257 trees/ha) followed by *Pterocarpus leucens* (9 trees/ha), *Anogeissus leiocarpus* (6 trees/ha) and *Tamarindus indica* (4 trees/ha). These three economically important woody species were found in all study areas along the river valley. A total of 17, 19 and 11 woody species were found at site I, II and site III, respectively grown in association with *B. papyrifera*. Of these, five species (*Anogeissus leiocarpus*, *Tamarindus indica, Pterocarpus leucens, Lannea schimperi and Acacia polyacantha*) were occurred in all study sites. The total densities of all the species were 202 individuals/ha, 189 individuals/ha and 108 individuals/ha at site I, II and III, respectively.

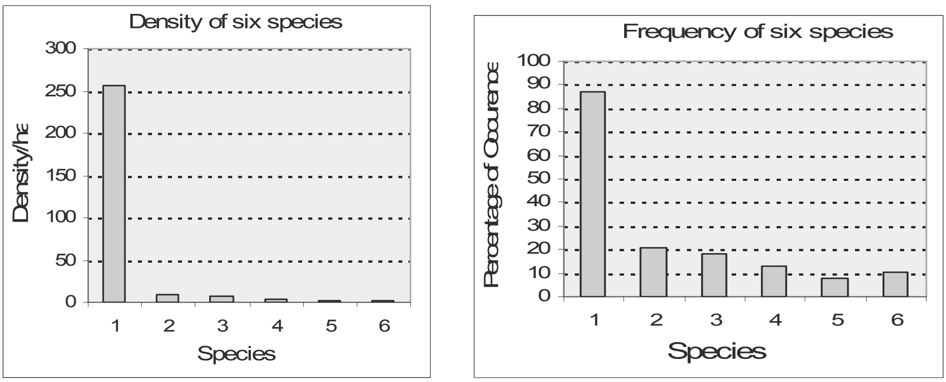


Figure 2. Density and frequency of six including *Boswellia* most important woody species in three sites located at Tekeze River Basin, Northern Ethiopia.

Where: *1 = Boswellia papyrifera, 2 = Pterocarpus leucens, 3 = Anogeissus leiocarpus, 4 = Tamarindus indica, 5 = Adansonia digitata and 6 = Acacia polycanta.*

Abundance and distribution of Boswellia trees at Tekeze river basin

The population density expressed on a hectare bases were 394, 225 and 152 individuals per hectare at site III, II, and I respectively. Similarly, site III, I, and site II had 92.3% and 76.9% frequency, respectively. It was also obtained a total density of (257 individuals per ha) and frequency (87.2%) of the three study sites (39 plots, 401 individuals) within the river valley along its entire altitude range (Table 1).

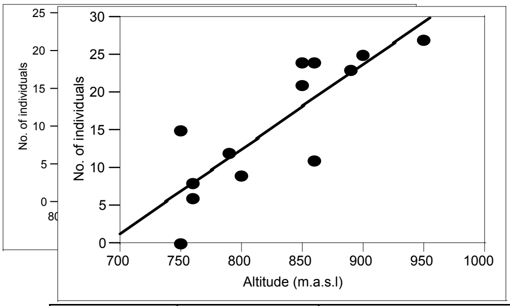


Table 1. Number of quadrates in each study site, number of *B. papyrifera* individuals encountered and corresponding densities and frequencies

Study site	Altitude (m)	No of		Density (ha)	Frequency (%)	No of Tapping
		Quadrates (ha)	individuals			
I	850-1250	13 (0.52ha)	117	225	92.3	no
II	850-1150	13 (0.52ha)	79	151	76.9	yes
III	750-950	13 (0.52ha)	205	394.2	92.3	no
Total	750 – 1250	39 (1.56ha)	401	257.1	87.2	

Effect of altitude, slope, and soil on abundance and distribution of Boswellia trees at Tekeze river basin

As indicated in Figure 2, more or less *Boswellia* trees were distributed along the whole altitudinal range of the river valley, with the highest record in the altitude range of 850– 950 m when all sites pooled (Figure 2d). Abundance of *Boswellia* trees were well explained (about 70% and 43%; significant at $P < 0.05$) by altitude in site III and II (Figure 2 b, c), respectively compared to site all areas and I pooled (Figure 2a, d).

As indicated in Figure 3, *Boswellia* trees were distributed within the entire slope range (4 – 82%) of the river valley, but gradually decreasing in number against the slope when all individuals of the three study sites pooled together (Figure 3d). In site II (Figure. 3b) a significant variation of *Boswellia* trees ($P < 0.05$), about 47% was observed due to slope difference compared to the other two study sites.

a) Site I, $R^2 = 0.27$ *b) Site II, $R^2 = 0.43$*

c) Site III, $R^2 = 0.70$
d) All sites pooled, $R^2 = 0.01$

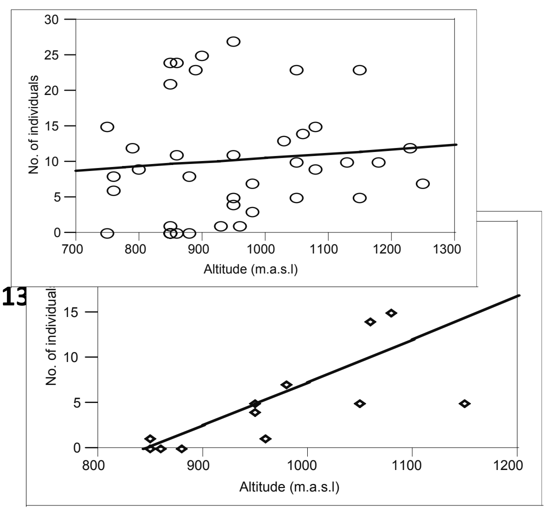


Figure 3. Number of *B. papyrifera* trees in relation to altitude per study site and all sites pooled. Symbols represent sample plots.

Regression lines are calculated for each study site and all sites pooled. Coefficients of determination (R^2) are indicated.

Probability of occurrence of *Boswellia* trees were decreased as altitude increased up to 1100 m a.s.l (Figure 4a). But the coefficient of determination (R^2) which is about 17%, shows the occurrence *B. papyrifera* trees along the altitude ranges of the river valley is not entirely dependent on altitude. Similarly, the relationship between the occurrence of *B. papyrifera* trees and slope ranges was found very weak (R^2 = 0.0003). Pearson's correlation coefficient of altitude and slope was also 0.17, which shows altitude is positively, but weakly correlated with slope.

a) Site I, R^2 = 0.001 *b) Site II, R^2 = 0.47*

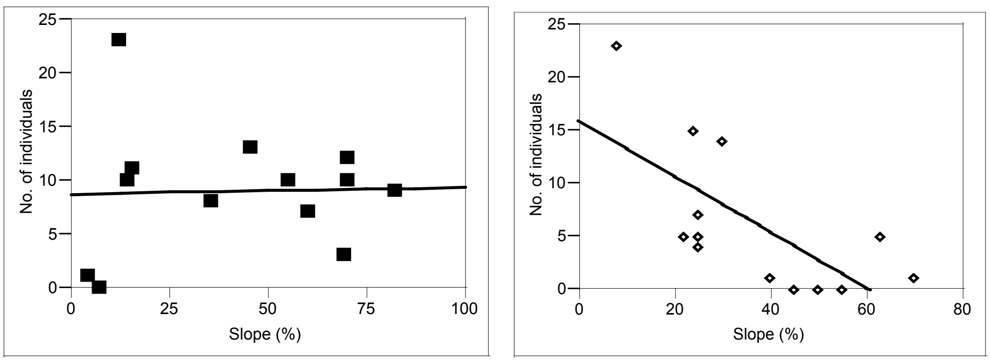
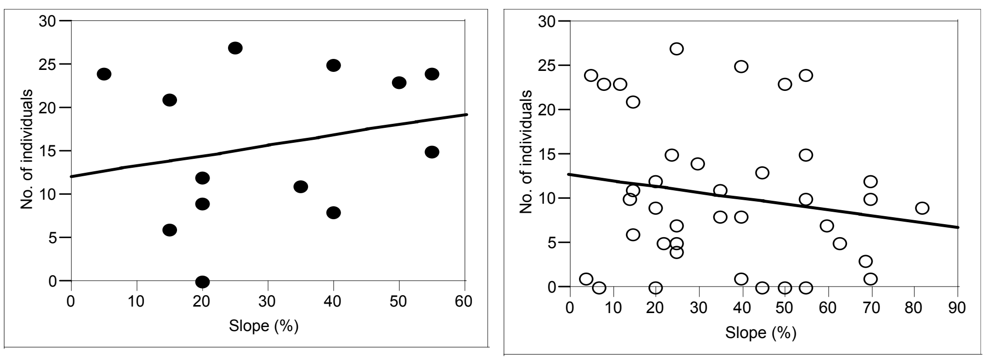


Figure 4. Number of *B. papyrifera* trees in relation to slope per study site and all sites pooled from Tekeze River Basin. Symbols represent sample plots. Regression lines are calculated for each study site and all sites pooled. R^2 is indicated

c) Site III, R^2 = 0.05 *d) All sites pooled, R^2 = 0.03*



a), $R^2 = 0.1741$ *b), $R^2 = 0.0003$*

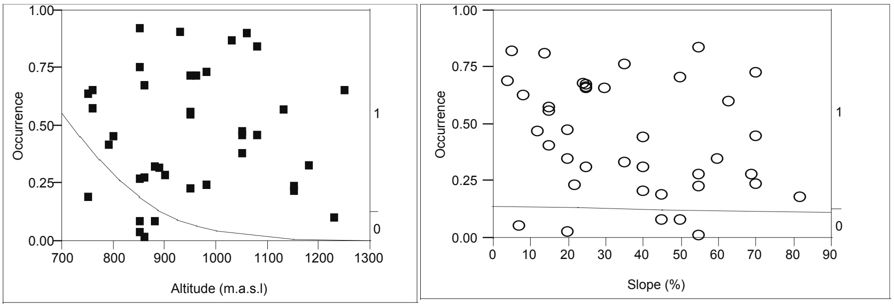


Figure 5. Probability of occurrence of *B. papyrifera* in relation to altitude (a) and slope (b) from all study sites pooled. Symbols represent study plots along Tekeze river basin. A probability of 1 indicates areas where the species is present; 0 where it is absent. Smooth lines are fitted logistic regression lines. R^2 is indicated. Pearson's correlation coefficient of altitude and slope was also 0.17

Table 2. Physical and chemical soil properties of the three study sites in Tekeze River Basin, Northern Ethiopia

	Study Area					
	Site I		Site II		Site III	
Variable	mean	Range	Mean	Range	Mean	Range
pH	6.6	5.8-7.7	6.7	5.8-7.3	6.7	5.5-8
EC (ds/m)	0.11	0.05-.32	0.09	0.02-0.18	0.12	0.04-0.31
Sand (%)	51.13	36.4-56.4	48.4	34.4-74.4	54.05	42.4-62.4
Silt (%)	37.13	27.3-43.3	37.3	19.3-45.3	35.13	27.3-43.3
Clay (%)	11.74	8.4-20.4	13.9	6.4-20.4	10.82	6.4-16.4
Total N (%)	0.03	0.02-0.06	0.07	0.02-0.17	0.08	0.03-0.19
Available P (p.p.m)	2.4	0.86-2.98	3.4	1.2-6.1	4.19	2.1-8.2
Exchangeable K (p.p.m)	16.06	6.7-24.7	50.2	10.7-101.1	47.53	10-99.6
Bulk density (g cm^{-3})	1.29	1.1-1.6	1.48	1.3-1.7	1.2	1.2-1.4
Organic matter (%)	2.14	1.4-2.4	2.92	1.2-4.5	2.31	1.4-3.2
CEC Cmol(+)/kg	14.29	6-19.02	13.18	4-21.5	6.02	4.1-7.6
TC-loam (%)	39		62		31	
TC-Sandy loam (%)	61		38		69	

Note: EC= Electrical Conductivity; CEC= Cation Exchange Capacity; TC= Textural Classification; P=phosphorus; K= potassium; N= Nitrogen.

The textural classification of soils (Landon, 1991) in the three study areas were found dominated either by sandy loam or by loam. In site I (39 and 61 percent of loam and sandy loam, respectively), site II (62 and 38% of loam and sandy loam, respectively) and site III (31 and 69% of loam and sandy loam, respectively) were found, when each study plots computed (Table 3).

Similarly, the mean bulk density (g cm^{-3}) of site I, II and III were found 1.29 (range 1.1-1.6), 1.48 (range 1.3-1.7) and 1.2 (range 1.2-1.4), respectively (Table 3). The mean organic matter content of each study site (site I=2.14, site II=2.92, and site III=2.31) were found relatively medium, but ranged from low to medium in site I and II and low to high in site III (Table 3).

Table 3. Pearson's correlation coefficients between numbers of *B. papyrifera* trees per sample plot and soil and topographic variables in the three study sites

Variables	**Site I**	**Study Site**		**All sites pooled**
		Site II	**Site III**	
Ph	0.25	-0.2	0.14	0.09
Electric conductivity (ds/m)	-0.47	-0.36	0.49**	0.14
Sand (%)	-0.01	-0.07	0.16	0.16
Silt (%)	0.05	0.13	-0.16	-0.08
Clay (%)	-0.05	0.06	-0.13	-0.17
Total N (%)	0.08	-0.33	-0.35	-0.15
Available P (p.p.m)	0.18	-0.49***	0.34	0.22
Exchangeable K (p.p.m)	0.16	-0.56**	0.21	-0.02
Bulk density (g cm^{-3})	0.27	-0.02	-0.12	-0.26
Organic matter (%)	0.11	0.18	-0.27	-0.07
CEC (Cmol(+)/kg	0.2	-0.38	-0.36	-0.39*
Altitude (m.a.s.l)	0.52**	0.66**	0.84*	0.09
Slope (%)	0.03	-0.75*	0.23**	-0.17

*Significant levels: * P < 0.01; ** P < 0.05; *** P < 0.1.*

The available phosphorus (P) were generally low in all sites, except for some plots that revealed relatively moderate available P values in site II (range 1.2-6.1) and III (2.1-8.2) as indicated in Table 3. When the three sites were compared, site III has relatively higher available P value. pH mean values of site I, II, and III were 6.6, 6.7 and 6.7, respectively. Moreover, mean values of exchangeable cation of site I, II and III were 14.29, 13.18 and 6.02 Cmol (+)/kg, respectively (Table 3). Among the environmental variables indicated in Table 4, only altitude was significantly ($P < 0.05$ for site I and II and $P < 0.01$ for site III) positively related to the number of *Boswellia* trees in all study sites. Values of available P and exchangeable K and slope were significantly but negatively related to the number of *Boswellia* trees in site II. Electrical conductivity and slope were also significantly related to the number of *Boswellia* trees in site III. Cation exchange capacity was also significantly but negatively related to the number of *Boswellia* trees, when all sites pooled (Table 4). Among the physical and chemical properties of soils considered in all study sites, the explained variation of the model was about 48%, mainly due to available P, cation exchange, exchangeable K, proportion of sand and silt. Moreover, the result indicated that the variation in the number of *Boswellia* trees in site II was explained highly (about 99%) by available P, exchangeable K, bulk density and organic matter ($P < 0.05$). A high (about 95%) variation in number of *Boswellia* trees in site III was also observed due to cation exchange ($P < 0.01$).

Table 4. Multiple linear regression analysis of physical and chemical properties of soils in Tekeze River Basin, Northern Ethiopia

Study site	Intercept	pH	EC	Sand	Silt	P	K	BD	OM	CEC	
	(a)	(b_1)	(b_2)	(b_3)	(b_4)	(b_5)	(b_6)	(b_7)	(b_8)	(b_9)	R^2
Site I	-75.35	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.45
Site II	-5.38	ns	ns	ns	ns	4.66**	-0.19**	67.2**	6.94**	ns	0.99
Site III	50.47	ns	ns	ns	ns	ns	ns	ns	ns	-2.64*	0.95
All sites pooled	-220.1	ns	ns	2.26***	2.47***	1.58*	-0.06***	ns	ns	-0.87*	0.48

$Y = a + b_{1\text{-}9}\,x_{1\text{-}9}$; where: y = number of *Boswellia* trees per sample plot; a = intercept;
$b_{1\text{-}9}$ regression coefficients for each soil property variables $x_{1\text{-}9}$; $x_{1\text{-}9}$ each soil property variables (pH, electrical conductivity, % of sand, % of silt, available phosphorus, exchangeable potassium, bulk density, organic matter and cation exchange capacity, respectively); Significant levels: * P < 0.01; ** P < 0.05; *** P < 0.1; ns (not significant).

Discussion

Results of the study show that though there are other important woody species, *B. papyrifera* was the most preferable and abundant species along the entire altitude and slope ranges of the valley. The population density expressed on a hectare bases in each study site was different. This variation might be occurred due the difference in management interventions and extent of disturbances. More or less *Boswellia* trees were distributed along the whole altitudinal range of the river valley, with the highest record in the altitude range of 850–950 m a.s.l. Similarly, it was distributed with in the slope range of 4–82%, but gradually decreasing in number as the slope increase. Kindeya *et al.* (2002) indicated that in Tigray, *Boswellia* trees, found in steep slope with an average gradient range of 30-40%. This study also found that in most cases *Boswellia* trees are denser in slopes ranged from 15–50% along the entire altitude of the river basin.

A total of 28 species were found in association with *B. papyrifera* in this study. Of these, *Pterocarpus leucens*, *Anogeissus leiocarpus* and *Tamarindus indica* were the most dominant and preferable tree species for fodder, construction and farm implements by the local inhabitants compared to other species. A comprehensive list of all species that were found along the entire altitude and slope covered by *B. papyrifera* at Tekeze river basin of each study plot was recorded and the floristic composition of each species in the study area was described in terms of presence (+) or absence (-). Studies conducted by Kindeya *et al.* (2003, 2004), Abeje *et al.* (2005) in northern Ethiopia and Ogbazghi *et al.* (2006) in Eritrea were found a considerable number of woody species grown in association with *B. papyrifera*. Moreover, they indicated that *B. papyrifera* was the most abundant species compared to other woody species in most of their study plots. Kindeya *et al.* (2004) also showed that trees with ≥ 10 cm DBH, *B. papyrifera* were by far the most dominant species in his study plots that fits with the findings of the present study. The present study indicated that the relationship between the probability of occurrences of *B. papyrifera* trees with altitude and slope is positive, but weakly correlated. Compared to altitude and slope, altitude was relatively has better and strong relationship with occurrence of *Boswellia* trees along the entire altitude of the river basin.

According to Landon (1991), values for bulk density, and fractions of sand, silt and clay found in the present study indicated that the textural classification of soils in all study sites were either sandy loam or loam. Among the environmental variables considered, altitude was found as the most influencing factor in the abundance of *Boswellia* trees along the entire altitude of Tekeze river basin. These findings were agreed with the findings of Ogbazghi *et al.* (2006), who dealt on the same species in Eritrea. In contrast, to this finding Ogbazghi *et al.* (2006) has found organic matter as the most important factor. This may be due site variation and management interventions. Though, there is a slight variation of soil property conditions among sample plots, values of available P, exchangeable K, and electrical conductivity were significantly but negatively related to the number of *Boswellia* trees in site II and positively in site III, respectively. The regression analysis models for all sites pooled shows thatthe explained variation of the model was about 48%, mainly due to available P, exchangeable cation capacity, exchangeable K, and fraction of sand and silt. Generally, the soil conditions of the river basin was dominated with low to medium organic matter content (1.2 -4.5%), medium to high pH values (5.5-8), low to medium available phosphorus (1- 8 p.p.m), and sandy loam to loam textural classifications.

Conclusions

Based on the present study, the following main conclusions have made.

- Results of the present study show that though there are other associated important woody species along the river basin*, B. papyrifera* was the most dominant and preferable by the local communities;
- *Boswellia* trees were distributed along the river valley in all study areas, but highly abundant within the altitude range of 850–950 m a.s.l. Similarly, *Boswellia* trees were occurred and distributed along the entire slope ranges of the river basin in all study sites, but gradually decreasing in abundance as the slope increase;
- **3.**The variation in occurrence, distribution and abundance of *Boswellia* trees among each study site along the entire river basin suggest that, management interventions/land uses and disturbances are more responsible for variations than other environmental variables (altitude, slope, and soil physical and chemical properties); and
- All study sites were dominated with low to medium organic matter content, medium to high pH values, low to medium available phosphorus, and sandy loam-to-loam textural classification. This reflects that the soil conditions of Tekeze river basin in general have no significant variation and relatively low fertile, but still potential for the growth and development of *Boswellia* trees and other woody and deciduous species.

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Appendices

Appendix 1. Density (number/ha) and frequency (%) of all woody and shrub species found in association with *B. papyrifera* along its entire altitude range in three study sites located at *Tekeze River Basin,* Northern Ethiopia.

Local name	Scientific name	Altitude Range (m.a.s.l)							
		750-850	850-950	950-1050	1050-1150	1150-1250	Status	D/ha	F (%)
Meqer	*Boswellia papyrifera*	+	+	+	+	+	T	257	87.2
Tsara	*Pterocarpus leucens*	-	+	+	-	+	T	9	20.5
Hanse	*Anogeissus leiocarpus*	+	+	+	-	+	T	6	18
Dimma	*Adansonia digitata*	-	+	-	-	-	T	2	7.7
Humer	*Tamarindus indica*	+	+	+	-	-	T	4	12.8
Gumero	*Acacia polycanta*	+	+	+	-	+	T	6	10.3
Mekie	*Balanites aegyptiaca*	+	-	-	-	-	T	6	5.1
Sebb-ae	*Combretum hartimannianus*	-	+	-	-	-	T	3	12.8
Dgwdgwng	*Lannea schimperi*	+	+	+	+	+	T	23	46.2
Zibbe	*Delbergia melanoxylon* +		+	-	+	-	T	6	15.4
Angole/Tagula/	*Commiphera tenuis*	+	-	-	-	-	T	1	2.6
Akumma	*Comparatum species*	-	-	+	+	+	T	5	15.4
Tenquelibay	*Comparatum fragrans*	-	+	+	-	-	S	6	12.8
Sessewe	*Combretum molle*	-	+	+	-	-	T	5	10.3
Unkakule/Unka-Hibey/	*Strychnos innocua*	-	-	+	+	-	T	3	7.7
Harmazo/Ayehaday/	*Securinega virosa*	-	+	+	+	-	S	6	10.3
Weiyba	*Terminalia brownie*	+	+	-	-	-	T	2	5.1
Quara/Ziwaw'e/	*Erythrina abyssinica*	+	-	-	-	-	T	1	2.6
Mesequa	*Grewia bicolor*	+	+	-	-	-	S	8	7.7
Dengerifa	*Londrocarpus laxiflorus*	-	-	-	+	-	T	2	7.7
Alendia	*Ormocurpum pubescens* -		-	-	+	-	T	1	2.6
Alongotsa	*Compratum adenogonium*	-	-	-	+	-	T	9	2.6
Afekemu	*Ficus hochstetteri*	-	-	+	+	+	T	5	7.7
Chea/Grar	*Acacia nilotica*	-	+	-	+	-	T	1	2.6
Ginda-e	*Calotropis procera*	+	+	-	-	-	S	4	2.6
Adgi-Zana	*Sterospermum Kunthianum* +		-	-	-	-	T	1	2.6
Hatsinay	*Gardenia lutea*	-	-	-	+	-	T	1	5.1
Gonek	*Dichrostachys cinerea*	+	+	+	-	-	S	40	25.6

*Where: T = Tree; S = Shrub; F (%) = frequency (number of quadrates occurrence/total number of quadrates *100), D/ha = Density per hectar.*

Trends and challenges of frankincense: the case of North Western and Western zones of Tigray Region, Northern Ethiopia

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Introduction

Ethiopia's rich flora diversity provides diverse Non-Timber Forest Products (NTFPs) that have economic and cultural values. NTFPs are collection of biological resources other than timber derived from both natural and managed forests and other wooded areas (Roderick P. Neumann and Eric Hirsch, 2000). Ethiopian lowland woodlands are rich with respect to tree and shrub species that offer commercial gums and incenses as NTFPs that have local, national, and international significance. They contribute to improved livelihoods of dryland local communities in terms of food security and income generation, while also contributing to the national economy being among the few export articles.

In Ethiopia, Gum Arabic, Gum Olibanum (Frankincense), Gum Myrrh and Gum Opopanax are produced. These products have a wide-range of industrial uses in areas such as beverages, pharmaceuticals, candies, chewing gums, confectioneries, dairy products, gelatines, nut products, puddings and canned vegetables (Kindeya *et al*., 2003; Mulugeta and Demel, 2003). Among these, the most widely collected and traded frankincense from Ethiopia is the Tigray Type frankincense, which is tapped from *B. papyrifera* mainly dominant in northern Ethiopia. Production of frankincense by individuals, private and government organizations for commerce has a long history in Ethiopia. Its use for ritual purposes goes back at least to the Aksumite Empire, 500 BC (Tilahun, 1997) and has ever since been continued by the Orthodox Church. Ethiopia was the main trader of frankincense with the ancient Egyptian and Phoenicians for more than 4000 years ago (Ahmed, 1982). Ethiopia and Somalia are also the major producers and exporters of frankincense (Farah, 1994). The sustainable use and correct valuation of frankincense and other NTFPs is a topic of increasing importance as more attention begins to be paid on the potential of forests to mitigate poverty in Tigray Regional State, which follows the agricultural led industrialization and export based production strategy. The low land areas of the Regional State, mainly its north western and western parts are highly recognized for their vast resource of frankincense/gum olibanum that has not been systematically managed, tapped, used, and documented. Despite the long history of frankincense tapping, processing and exporting, the culture of resource assessment and inventory to quantify the actual and potential production trends, marketing trends, overall challenges, and opportunities in the region in general and its northwestern and western zones in particular is lacking. There is also limited information in the actual and quantified production and organization involved in production of frankincense from districts of north western and western zone of the region. The information on its contribution to the regional economy is also very limited, but very crucial for sustainable management and utilization of *B. papyrifera* and its frankincense. Therefore, this study tried to fill the knowledge gap on the existing challenges and production trends of frankincense in the region in general and in its north western and western zones in particular.

Materials and Methods

Study area

The study was conducted in the dry forests of north western and western zones of Tigray Regional State, where *B. papyrifera* that produces frankincense or gum olibanum naturally exist. Plains and rugged topography characterize the relief of their agro ecologies, which includes hot to warm semiarid low lands (SA_1), hot to warm sub-moist low lands and river gorges (SM_{1-4}) and tepid to cool sub-moist mid-highlands (SM_{2-5}), mountainous and plateau (TARI, 2002). The dry forests of north western and western zones of western Tigray are rich in natural trees and shrubs especially along the Tekeze and other major river basin. Most shrubs and trees of the area are deciduous and xerophytes in nature that have an adaptation to the limited rainfall and prolonged dry season.

The *Boswellia, Commiphera*, and *Sterculia* species are found on slopes that are relatively steep with an average slope of 30–50% and covering hillsides and river basins (GTZ, 1998). It was also indicated in the same document that the dominant soil types are Vertisols, Eutric Cambisols, Chromic Vertisols and Vertic Luvisols. In addition to *B. papyrifera*, which lies in the *Acacia-Commiphera* and *Combretum-terminallia* wood lands and river basin, *Diospros mespilifomis, Combretum collinum, Anogeissus leicarpus, Dchrostachys cinerea, Ziziphus spina-christi, Balanites aegyptiaca, Ficus hoschstetters, stercwia setigera*, etc., are the major tree species found in the study areas. The north western and western zones of Tigray encompass six weredas or districts, (*Tselemti, Asgede-Tsimbla, Tahtay-Adiabo*, *La'elay-Adiabo*, *Tah'etay - Koraro* and *Medebay-Zana)* and three weredas or districts *(Kafta-Humera, Wolkait and Tsegede*), respectively. The first three from north western and two from western zones of are denser in *B. papyrifera* coverage and have been practicing better production and marketing activities of frankincense by the locally established cooperatives, trading companies and one governmental enterprise.

Methods

The study was undertaken at different levels. General information on the over all challenges, opportunities, and production trends were compiled at local, district, zonal and regional level. Detailed information (preliminary and secondary) on production, and harvesting trends and over challenges of frankincense were collected from regional, districts/weredas of north western and western zones of Tigray and locally established cooperatives, trading companies and governmental enterprise involved in the collection, processing and marketing of frankincense. These include mainly, *Tselemti, Asgede-Tsimbla* and *Tahtay-Adiabo* weredas/districts, the National Gum Processing and Marketing Enterprise and Sihul Share Co. of Shire Branch. It was conducted by employing focused group discussions, key informants suggestions, in-depth interviews using checklists and collection of secondary published and unpublished data from concerned finance bureaus, private and governmental trading organizations. Data were analyzed using descriptive statistical methods.

Results and Discussion

Resources potential of frankincense production

Discussants and previous studies indicated that the total area coverage of *B. papyrifera* and other dryland economic tree and shrub species in the region has been declining from time to time due to many reasons. As indicated in Table 1, this resource is found in 15 administrative weredas of the region including the areas currently with limited coverage of the resource. Of course, accurate and comprehensive information on area coverage, population density and frankincense production is lacking.

In the late 1970s, about 510,000 ha of land were covered by *B. papyrifera* in Tigray (Wilson, 1977). GTZ (1998) has also indicated that the resource potential of *Boswellia* forest in north western and western administrative zones is around 948152 ha. But, currently the resource is becoming declining in alarming rate due to different threatening factors including shifting cultivation, fire, free grazing, inappropriate land use system, the wrong approach that focused only on tapping and collection of the product and charcoal production, in the aforementioned localities in particular and the region as a whole.

Table 1. *Boswellia papyrifera* distribution by wereda/district and kebeles of Tigray Region

Wereda	No. of Kebeles having the species	Coverage (ha)
Kafta Humera	9	93880
Wolkait	10	91140
Tahtay Adiabo	6	95270
Asgede Tsimbla	10	5014
Tselemti	6	48125
Tsegede	7	2752
Laelay Adiabo	7	739
Medebay Zana	5	1705
Naeder Adet	6	1421
Mereb lekhe	8	1188
Weri lekhe	6	1012
Quola Temben	13	668
Tanquq Abergelle	10	1592
Saharti Samre	6	1567
Degua Temben	3	987
Total	**113**	**347060**

Source: Bureau of Agriculture and Rural Development, 2008

Inventory results from Tekeze River valley indicated that, the population density expressed on a hectare bases were 394, 225 and 152 individuals per hectare at *Kafta Humera, Asgede Tsimbla* and *Tselemti*, *respectively*. It was also obtained a total mean density of 257/ha and frequency of 87.2 % with in the river valley along its entire altitude range of the three administrative districts (Table 2). The population difference is mainly attributed due to the difference in land use systems and other natural and human induced factors.

Table 2. Density and frequency of *Boswellia* trees at different altitudinal range of Tekeze river basin in north western and western zones of Tigray

Wereda	**Altitude (m)**	**Density (ha)**	**Frequency (%)**
Tselemti	850 – 1250	152	76.9
Asgede Tsimbla	850 – 1150	225	92.3
Kafta Humera	750 – 950	394	92.3
Total	**750 – 1250**	**257.1**	**87.2**

Production Trends of Tigray Type frankincense

Some historical documents indicatd that incense was among the major export commodities during the pick civilization era of the Axumite Kingdom. As evidence, it is quoted in ancient documents that frankincense was one of the gifts offered to the famous King Solomon of Jerusalem when Queen Sheba visited him. Later after a long period of rest, the production was restarted in the region in 1940's during the Italian invasion by some individuals who came from Somalia around *Mereb Lehe*, *Tselemti, Asgede-Tsimbla*, *Laelay Adiabo* and *Tahtay Adiabo* weredas until the production was started regularly by a company known as TAIDL (Tigray Agricultural and Industrial Development Limited.) in 1961/62 (Tilahun, 1997; GTZ, 1998). TAIDL was nationalized and stayed in the business up to 1974.

National Gum Processing and Marketing Enterprise (NGPME) was established in May 1976 by the Derg regime and has been collecting and marketing natural gum both frankincense and gum Arabic as a sole government enterprise in Ethiopia, until the fall of the Derg regime in 1991. After 1991 following the introduction of market economy, other organizations, private investors, share companies and cooperatives have shown interest to involve in the production process. Currently, there are about four private trading companies (*Sihul, Allula, Selam and Guna)* and *one privet investor* actively involved in the production and processing of frankincense in Tigray other than NGPM enterprise. Moreover, there are a number of local cooperatives (Table 3) established in each weredas of North Western and Western Tigray, where *B. papyrifera* is naturally existing and actively involved in the production and marketing of frankincense.

Table 3. Number of cooperatives established in different administrative districts of north western and western zones of Tigray

Wereda	Zone	Number of cooperatives
Tselemti	North Western	2
Tsegede	Western	3
Wolkait	Western	11
Kafta Humera	Western	14
Tahtay Adiabo	North Western	13
Laelay Adiabo	North Western	1
Asgede Tsimbla	North Western	5
Total		49

Source: Survey result from of each administrative district, 2008.

The Tigray type gum olibanum or frankincense is playing significant economic role both at the local and national levels, and its contribution is growing every year. In fact, natural gums are among the major forest derived export commodities that Ethiopia owns. Indeed, the direct national economic contribution of the dryland vegetation resources through provision of gums and gum resins, in terms of generating foreign currency, far outweighs that of the forest resources in the humid and sub-humids together in Ethiopia (Mulugeta and Demel, 2003).

Even though, frankincense production in Ethiopia is as old as the recorded Ethiopian history that dates back to the Axumite Kingdom. However, information on production status and trend is not documented because of many reasons. Fragmented and mostly rough approximations are what can be obtained. Mulugeta (2005) indicated that the total area of woodlands and bush lands comprising gums and gum resins bearing species cover some 3.5 million ha in Ethiopia, with the production capacity of over 300,000 metric tons of natural gums. It is very difficult to quantify the actual annual production in the study area due to many reasons.

The NGPME, which is a state owned enterprise and major producer of natural gums in the country is probably the only office that maintains a good record of its production. The problem with the export quantification is that it aggregates all sorts of gums and gum resins such as frankincense, myrrh, opopanax, balsam, and others into a single commodity, making the statistics on individual gums and gum resins difficult to obtain. In Tigray Regional State the actual annual production is very low when compared with the potentials of the region. Generally, the production trend of the Tigray type frankincense is declining through time in the region when compared with the existing potential in the Region. According to Tilahun, (1997) and Girmay (2000), the production potential of Tigray type olibanum is 26,630 - 88,770 tons from an estimated total area of 940, 000 ha. Concerning the amount of the Tigray type frankincense, there was no strict follow up and the following data was collected from the producers based on what they report. According to this report, the quantity of Tigray type frankincense produced in the last 15 years is indicated in Figure 1.

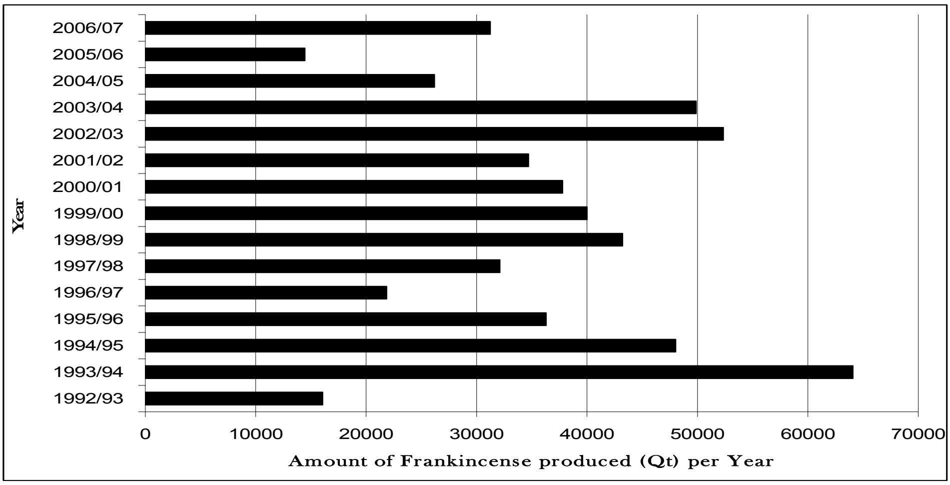

Figure 1. Production trend of Tigray type frankincense for 15 years (between 1992/93 and 2006/07) in Tigray Regional State

Source: *Tigray Bureau of Agriculture and Rural Development, 2008*

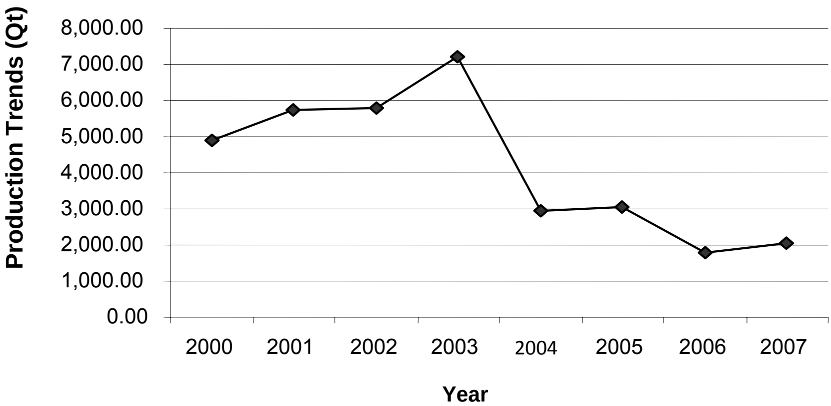

Figure 2. The amount (q) of Frankincense collected from *Tselemti* and *Asgede-Tsimbla* weredas of northwestern Zone of the Tigray between 2000 and 2007 by NGPME – Shire Branch

*Source: Interview with NGPM enterprise during the field study, 2008;** 1 quintal = 100 kg.*

Table 4. The amount (q) ** of White and Black *Gireazo* raw product of Frankincense between 1994 and 2007 from northwestern zone of Tigray

Year (EC)	Amount collected in quintal		
	White *Gireazo*	Black *Gireazo*	Total
1993/94	4,800	252	5,052
1994/95	5,000	300	5,300
1995/96	2,800	150	2,950
1996/97	3,640	1,273	4,913
1997/98	3,829	1,553	5,382
1998/99	7,933	690	8,623
1999/00	4,667	2,213	6,880
2000/01	3,642	1,684	5,326
2001/02	6043	760	6803
2002/03	5019	554	5573
2003/04	3460	331	3791
2004/05	2627	224	2851
2005/06	1358	163	1521
2006/2007	1412	144	1556
Total	**56230**	**10291**	**66521**

*Source: Interview with Sihul Share Co. during the field study, 2008;**1 quintal = 100 kg, E.C =Ethiopian Calendar.*

Challenges/constraints

Though *B. papyrifera* and its frankincense have multi-service functions as discussed in the earlier topics, there are also a number of challenges different in nature at the ground affecting the production trends. The prominent challenges are either of the following categories

Organizational/institutional factors

- Irregular conflict among users that leads to illegal marketing;
- Lack of access roads/infrastructures that deteriorates the product quality;
- Lack of efficient services (food, water, medicine e.t.c.) for collectors that may have its influence on quality product locally called '*Gireazo'*; and
- Present interest on the sector is maximization of frankincense quantity through intensive tapping and there exist very little interest in construction of small industries for value added processing

Socio-Economic and management related factors

- The rate of payment for collectors depends on their production amount which implies for exploitation of the tree per annum with low product quality that have its influence on marketing;

- Huge and expanding encroachment such as free grazing, fire and illegal seasonal farming practices or ploughing the resource area with out permission and legal land holding certificate every year locally called *'Wefer Zemet'* that declines the product amount and marketing trends;
- Poor knowledge on marketing of frankincense by local communities lead to very limited involvement in tapping and collection that could be an indicator of unsustainablity of the species and its product; and
- Lack of trained labour force in tapping and collection affecting the quality and quantity of products and resulting in high mortality of the species and depressed volume of production.

Policy and administrated related challenging factors

Little attention from the policymakers side to develop and implement strategies of sustainable development, marketing chain and conservation of the species that have been promoted only to maximize exploitation of the plant product with out a view to long-term development.

Licenses were issued for short term usually one year that did not give security to the user and resulting in maximization of the quantity with out any consideration for the future sustainability of the product.

There was lack of clear guideline on the subsequent activity of the user (cooperatives, private investors, and organizations) beyond investment endorsement.

In spite of the aforementioned challenges, the respondents indicated that B. *papyrifera* and its frankincense can serve as local employment opportunities, export earnings, bee keeping, livestock fodder, and medicinal values. Moreover, it plays a great role in saving the fragile arid and semi-arid lowlands from desertification and other environmental vulnerabilities.

Conclusions

Based on the present study the following conclusions have made:

- The most widely collected and traded frankincense from Ethiopia is the Tigray Type frankincense, which is tapped from *Boswellia papyrifera* mainly dominant in northern Ethiopia in general and northwestern and western parts of Tigray region in particular;
- Even though, production of frankincense in the present study areas has a long history, regular collection and trading was started in 1961/62;
- The total area coverage of *B. papyrifera* and other dryland economic tree species in the study areas has been declining from time to time due to different

threatening factors including shifting cultivation, fire, free grazing, inappropriate land use system, wrong approach that focused only on tapping and collection and charcoal production;

- The production trend of frankincense is declining through time when compared with the existing potential. The major factors affecting the production and the annual production quantity of frankincense include, lack of access roads, poor collection of frankincense, poor documentation, lack of control and follow up, complete dependence on the traditional tapping system, short leasing, illegal harvest and trade and sometimes conflict among producers;
- Production of frankincense has been contributing its role in job opportunity creation and income generation to attain food security at household levels;
- Production of frankincense has a great contribution to the weredas and/or regional economy and the well - to do group of people. However, this study indicated that the collection of frankincense in the area has no direct benefit for the local people except those involved in guarding and transporting of the raw product mainly because of cultural influence, resource ownership problems, lack of experience on its sustainable production and lack of awareness of the business;
- The regional bureau of agriculture and rural development has banned *B. papyrifera* from cutting and well recognized that the resource base is diminishing. Thus, the bureau with a firm stands of conservation and sustainability has proposed as only utilization focused production system should stop before the resource completely disappears;
- The respondents indicated that B. *papyrifera* and its frankincense can serve as local employment opportunities, export earnings, bee keeping, livestock fodder, and medicinal values. Moreover, it plays a great role in saving the fragile arid and semi-arid lowlands from desertification and other environmental vulnerabilities; and
- The nature of the species, organizational/institutional factors, socio-economic and management related factors, policy and administrated related factors and marketing related challenges that differ in nature at the ground have been also affecting the production trends of frankincense and existence of the study species.

Recommendations

Based on this study the following recommendations have set for their implementation:

- An inventory control mechanisms should be established in the region to quantify the actual and potential annual production of frankincense to each wereda and the region as a whole and its actual significance to the local inhabitants and other user groups;
- Local and regional polices should be formulated and implemented through participation and consultation of local individual farmers, cooperatives or unions

and enterprises or organizations involved in production and marketing of frankincense;

- Protection of *Boswellia* stands from external factors such as free grazing; shifting cultivation, continuous and inappropriate tapping setting of fire and others must be supported by setting appropriate land use, strict policies, rules and regulations;
- Obligations and responsibilities to frankincense producers and traders should be specified and attached in order to protect damage to *Boswellia* trees and its frankincense and actively participate in its development for sustainable management and find means and ways to benefit the local communities and the country at large;
- Efforts should be made to increase the socio-economic significances of the tree at different levels by setting rules and regulations that permits the production and marketing of frankincense under long leased license supported by management plans to manage and develop the resource with subsequent penalties if otherwise;
- The government should ensure market chain governance, combating illegal trades and comprehensive awareness creation at different levels to bring common interest on frankincense producers; and
- Further research on value chain and/or value added processing of frankincense, on insuring local communities' participation, benefits, economic and ecological valuation of *Boswellia* tree with alternative land use systems like agroforestry is indispensable.

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Other Non Timber Forest Products

Survey of Non-Timber Forest Products in Western Oromia

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Introduction

Non-Timber Forest Products (NTFPs) are one of the three major product functions of the forest timber product function, non-timber forest products and service functions. It is the biological material (other than industrial round wood and derived sawn timber, wood chips, wood-based panels and pulp) that may be extracted from natural ecosystem, managed plantation, etc, and be utilized within the household, be marketable, or have social, cultural or religious significance.

NTFPs are plants or plant parts that have perceived economic or consumption value sufficient to encourage their collection and removal from the forest. That is, they are those items harvested or removed from the forest lands for private use or for resale (excluding, saw timber, pole timber, natural gas, oil, sand, gravel, shale and building stone all of which are covered under other sections).

NTFPs are important source of food, medicine, fodder, income, job opportunities, and raw materials for industries. Their major contributions can be generalized as, potential to the conservation of tropical forests: to improve the livelihood of forest dwelling people and their potential for participatory forest management (Ros-Tonen, 2001). Having these major functions, the contribution of NTFPs to the country in general and to the western Oromia in particular is under estimated and less attention. Therefore, considering the role of NTFPs in national and local economy, as well as the change in global scenario, a country like Ethiopia should give adequate attention to the development of the technology.

NTFPs have significant function in generating income for the local households, national and international level. NTFPs play an important role in national economy as revenue earning source. Some NTFPs are traded internationally, some are traded only in local markets, where as others are consumed directly by the harvester. All three groups of products are valuable to the economy as they provide scarce resources, which would otherwise be either lost or produced through expensive means, (Mendelsohn, 1993). Presently, at least 150 NTFPs are internationally traded (FAO, 1997). Among them are nuts, honey, palm heart, plant, and animal inputs to the pharmaceutical industry, rattan, bamboo, cork, essential oils, and gum Arabic.

Some of Ethiopia's NTFPs such as honey are exported and about half of the officially traded volume belongs to gums and incense. Hence, they are cash forest products that contribute a major share to rural household economy, (RECOFTC, 1995). Men and women also have differing roles in collecting NTFPs. In southwest Bengal, Malhotra et al. (1993) found that women constitute the major gatherers of forest products - particularly fuelwood and fodder and other items for domestic consumption, while a few elderly men usually collect medicinal plants. Some men gather dry leaves and fodder. Most women also take their children to the forest to collect tubers, brushwood, and dry leaves. Studies show that NTFP-based activities can provide women with a greater sense of self-confidence and improved status within the household and the community (Marshall *et al.,* 2006a). Forests are also considered an important source of food that is included in NTFPs. The food value of forest is due to the importance of maintaining the needs of the local people in securing the household food demand. Food from forest and other tree systems constitute an important component of household food supply (Pol, 2002). In Nigeria, food security of rural dwellers is improved by growing trees in the home gardens and on farms. Leaves, rattan, honey, sap, gums from the small scale industries are important sources of income (Okafor *et al*., 1994). Having this all varied uses and servies, the contribution of NTFPs to the local or national community has not yet received. In general, in Ethiopia and particularly in western Oromia NTFPs has less attention due to many reasons, starting from that point the survey on the availability and uses of NTFPs are demanding for Western Oromia.

Materials and Methods

The survey was conducted in three zones of Western Oromia namely West Shewa zone (Chaliya), H/G Wellega zone (Horro, and Abay choman) and West Wellega zones (Hawa galan and Anfilo) districts. From each districts two PAs' wereselected randomly.

The secondary data was collected from relevant stakeholders and reconnaissance survey including site selection was made to identify the major NTFPs available in each district. Data collection was carried out in informal survey using different PRA tools (Group discussion, individual interview, key informant interview, transect walk, etc) based on checklist as a guide; and focused formal survey also carried out based on structured questionnaire prepared for this purpose.

Data analysis

The data were entered into the computer using data processing application in software Excel and analyzed using the SPSS soft ware program. Data obtained from unstructured interviews were described and presented qualitatively. The data gathered by structured questionnaire and analyzed using SPSS. The specific methods of data analysis involved description of background variablevariations in simple percentage analysis.

Results and Discussion

A structured questionnaire was used to interview 102 farmers from the five districts. More than 84.3% of the interviewed households in all districts during the survey are male.

Among the interviewed 19.6% pursued adult education, 39.2% elementary education, 19.6% high school education, 2% above high school education level and the remaining 19.6% were illiterate.

Concerning about planting of different tree species around homestead few people were not practiced among the interviewed, this was due to the absence of seedlings. Nevertheless, the rest were practiced by obtaining seedlings from nearby nursery site and also some are raise different exotics and indigenous tree species around their homestead, these practices is good habit.

All the respondents explain, as the natural forest exists in their vicinity. From those respondents about 91.2% are know that forest is owned by government, the rest 8.8% says they know some part of forests is owned by the communal. The result also showed that they use forest products for different purposes. Different forest products are used: for fuel wood consumption, fruits, for farm tools and for other purposes. There is also illegal logging and use of forest products. Despite that, the government is giving great attention for natural resources and efforts being done on the issue of climate change. so from this point of view our country needs to focus on natural resource protection and sustainable use otherwise the resource that we have on hand today will be lost within short period of time. The interviewee's indicated as they used forest products for different purposes such as fuel wood, farm tools, for construction, root for fencing, for medicinal value, for food source and other unmentioned values.

The results showed that in all areas different types of wild food trees used as a food source. From those tree species listed by the respondents namely: *Ficus sur*, *Syzygium guineese*, *Cassia siamense* and *Rosa abyssinica* are some of the major edible fruit trees found in the forest almost in all areas. According to the demand for tree species mentioned above *S. guineese* is ranked first in its preference in the society, mostly by children and also this specie is highly demanded in the society for its used as cash income.

Regarding to wild coffee products from all surveyed districts the resource is observed only in two districts Hawa Galan and Anfilo. Among the interviewed about 12.5% of the respondents from Hawa Galan district use this wild coffee product for house hold consumption and cash income and also the rest respondents about 7.4% are from Anfilo district. Moreover, plants are an indispensable source of human and livestock medicinal preparations, both preventive and curative. Ethiopia is endowed with a wealth of plant species with high potential to produce herbal and plant derived drugs. Traditional medicine as one of the most important NTFPs has an important place in the health care of Ethiopian population. Having said this all about medicinal plants in the study area almost 84.3% of the respondents use those species for medicinal purposes. Species used for medicinal value and wild food source are listed below in the Table.

Table 1. Types of wild food source plants and medicinal plants

Purpose of Species					
Wild food source plants			Medicinal plants		
Scientific name	Local name Oromifa	Local name Amharic	Scientific name	Local name Oroifa	Local name Amharic
Ficus sur	Harbuu	Shewal		Hancabbii	Demakase
Syzygium guineese	Baddeessaa	Dokma		Qarabichoo	----
Cassia siamense	Agamsa	Hagam	*Crotan macrostachyus*	Bakkanniisa	Bisana
Rosa abyssinica	Goraa	Enjori	*Purnus africana*	Hoomii	Tikor inchet
Cordia africana	Waddeessa	Wanza	*Clausena anista*	Ulmaayi	-----
	kara wayyuu	------	*Erythria brucei*	Waleensuu	Korch
Phoenix reclinata	Meexxii	Zembaba			

The study indicated that in all the surveyed areas, the potential of NTFPs is high but, there is no habit of using the products as required.

Mushroom is one of the NTFPs and the potential food plant found almost in all the surveyed areas. About 76.5% of the respondents only know the availability of mushroom in their area. However, the rest 23.5% of the respondents do not know what mushroom is. Depending on this result, about 28.4% of the respondents only know the availability of this product and use as food for household consumption. Moreover, the rest 71.6% of them are do not habit using this resource as a food. Almost all respondents indicated that they have no knowledge on how to process mushroom product for household consumption except using traditionally. Concerning wild animal products almost all of the respondents use directly or indirectly. The type of wild animals used for different purposes are Bush buck, Duiker, Pig, Porcupine and Partridge In general, the respondents said that they use wild animal products mainly for two purposes, first, for house hold consumption (Food and cash income) and secondly, for medicinal values. Concerning the civet mask product, the result from the survey indicated that it is available in all areas. Nevertheless, they do not use the product as required. Among the respondents, about 10.5% only know the availability of civet cat in the area. But the rest about 89.5% they have no information.

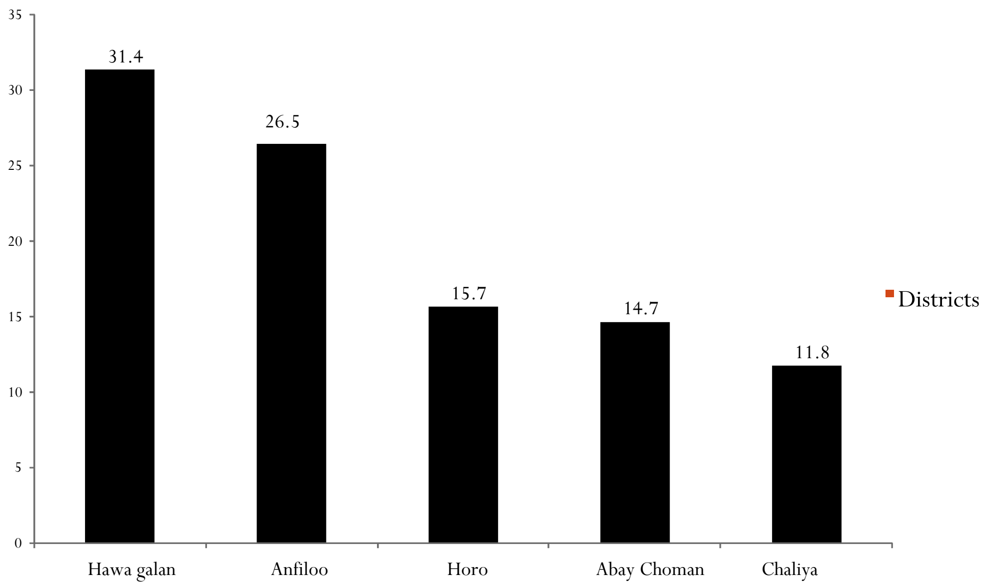

Figure 3. The availability of Civet mask according to the respondents from all surveyed areas.

According to the results from all surveyed sites, Hawa Galan has better potential of civet mask production when compared to the others. As indicated above those people who collect and use the product they harvest from trees. From those collectors about 8.3% use products only for local market purpose, but the rest use for house holds purposes.

Concerning the bamboo species, about 66.7% of the respondents use bamboo products for different purposes. The community uses bamboo mostly for local construction beehives; house, basket fence and other house hold furniture. It is also used for cash income, by selling the uncrafted stem. According to the respondents, highland bamboo species is 29.9%, lowland bamboo species is about 53.7%, and the rest say *Arunda Donax* (shamboqo). The nature of this bamboo species differ from place to place like: plantation and natural grown. About 29.9% say that they use the natural grown one and about 51.6% of the respondents said that they usedthe plantation. It is therefore clear that from time to time people are developing the practice of planting trees around their home and farmlands. In general, we observed in some areas the community use bamboo products for market/cash income purpose.

From the survey we also found that bee forage exists in all surveyed areas almost the same tree species used for this purpose are *Vernonia amagadlina, S. guineese, Schefflera (Gatama* local name*), Pouteria adolfi-friederici* nd *Eucalyptus.*

Conclusions and Recommendations

The results of this paper mainly focus in identifying the potential and contribution of Non Timber Forest Products in Western Oromia. The potential resource is found and how this resource is contributed for household food security. In general, almost all of the respondents know the products but the problem is that not utilizing efficiently as required. The results of these findings showed that almost in all areas the communities have no enough knowledge about NTFPs uses and values. But simply they use the resources. As we all know, the contribution of NTFPs has a great role in household food security and income generating, in the country particularly in the study areas. But as the results indicated that in all areas no one use and practices the resource efficiently due to lack of awareness. Concerning mushroom product, the community used for household consumption but in traditional way.. This will play a great role in conserving our resource and in food security program.

These people practice cultivation and depend on forests for their livelihood needs. An underlying assumption is that communities will conserve and protect forest resources if they receive tangible benefits from sustainable utilization of forests. Generally, the major bottlenecks affecting productivity of NTFPs is poor market access and infrastructure. Improving the existing poor market infrastructure will simultaneously solve related problems that limit the development potential of the study area. Unfortunately, forest coverage and forest resources of the study area are declining, which may affect future prospect of sustainable NTFPs and thus livelihoods. In this regard, concerted efforts from all actors are needed to reverse the situation through an appropriate forest management strategy. Starting from this study we recommend for the future concerning about NTFPs found in Western Oromia

- The contribution of NTFPs to the household income is often overlooked in various economic and conservation surveys. However, in practical the role of NTFPs to rural household economy is significant. It is recommended that policies and strategies that aim at improving the welfare of rural people and natural resource conservation should give attention to the contribution of NTFPs to the local people. Moreover, Government and NGOs should support and encourage NTFPs and NTFPs- based activities as part of the diversified livelihood strategies;
- Once the availability of the resource is identified, the next step is on how to commercialize these resources must be considered. Local markets are guarantee way of reaching some of the poorest people and play a crucial role in strengthening livelihood and improving income opportunities. It is recommended that policies or strategies aiming at improving marketing facilities for NTFPs. Market infrastructure be given due priorities; and
- The government must focus on NTFPs resources available in the country in general and particularly in Western Oromia because the potential of the resource is high.

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Establishing Value Chain Model to Commercialize Moringa Production

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Introduction

Moringa was one of the most neglected, and hence non-traded commodity in general sense in Ethiopia. Its use and level of consumption is very low and is restricted only in few areas of Southern Nations, Nationalities, and Peoples Regional State. Limited awareness on the importance of *Moringa* is the most attributable factor for its low level of use and consumption. *Moringa* is very much known in many parts of the world for its nutritious content containing several nutrients (essential amino acids, vitamins, and minerals) that are necessary for healthy and productive life (Barminas J.T.; Charles, Milam; Emmanuel, D, 1998). The nutritional content makes it one of the best alternative commodity to ensure food and nutrition security. Despite its massive potential in addressing food and nutrition insecurity problems, *Moringa* has remained unutilized and neglected commodity in Ethiopia. As it is rich with essential nutrients, it can play vital role in curbing malnutrition problems persistent in many areas of the country.

Recognizing such enormous potential of the species, a project that aimed at commercializing *Moringa* production through establishing its value chain was implemented in Alamata woreda, of the Tigray National Regional State, located 600 km North of Addis Ababa. Agroecological condition of the woreda is suitable for *Moringa* production and the tree is abundantly available throughout the woreda giving no benefit other than just serving as a shade tree. The woreda has no previous experience on utilization of *Moringa* attributed to limited awareness on importance and enormous potential of the species to address many of the persistent problems prevailing in the woreda, i.e malnutrition, unemployment, limited opportunities for self-employment, and income generating opportunities particularly for women (Source of this information is discussion with various woreda offices).

The demand/consumption of *Moringa* products has substantially increased in different parts of Ethiopia, and supply of Moringa products from Alamata areas is increasing. The current price of one kilogram of Moringa in Addis Ababa market ranges between 140 and 300 Birr. The project is pronounced to be a successful project meeting all its predetermined objectives of commercializing *Moringa* production in Ethiopia.

This paper, therefore, presents the experience gained in materializing such enormous potential of *Moringa* by establishing and developing its value chain and integrating women in the entire value chain for their benefit.

Benefits from Commercialization of Moringa

Various research undertakings reveal that the nutritional status of *Moringa* has high potential to address food and nutrition problems, which are very much persistent in Ethiopia (Abuye et al., 2003). The development of its value chain helps improve supply of various products of *Moringa* both in rural and urban areas so as to addressing food and nutrition security issues. The benefits that *Moringa* may provide can be classified into three categories.

Benefit to participating target groups (self-employment, increased income)

Self-employment and increased income are the direct benefits for targeted beneficiaries involved in *Moringa* value chain (Morris, 2001). Women integrated in *Moringa* value chain particularly in processing and marketing of various *Moringa,* products in Alamata Woreda have earned substantial income. Average income earned by the women beneficiaries engaged in *Moringa* business ranged from 1500 to 3000 Birr/month and their income have shown tremendous growth during the last two years since they started the business. The commercialization process and the development of its value chain provided more self-employment opportunities for large number of unemployed citizens both in rural and urban areas.

Benefit to the entire society (Improved health, food and nutrition security)

The production as well as the consumption of *Moringa* is expanding in many areas of the country that is a direct impact of the project intervention and are growing at a higher rate during the last two years. As the level of awareness and subsequent consumption of Moringa increases, the overall health status of the entire society will get improved. The feedback received from several individuals confirms that *Moringa* has a considerable impact of improving their health status. The increase in production of *Moringa* contributes to meet food and nutrition requirement of rural and urban communities. Increased consumption particularly by children prevents or reduces malnourishment problems persistent in many parts of the country. Expansion of Moringa plantation, which will take place following growing interest of farmers and private investors, improves the vegetation cover, which is a benefit to the ongoing environmental rehabilitation efforts in the country.

Benefit to the national economy (Long term)-Export earning

The export earnings from *Moringa* is a long term benefit that can be attributed to the project. Moringa is at present being traded only in local market. Various Moringa products unlike the situation three years ago have now become available in Addis Ababa Market. This is made possible through the different sales point. The long-term benefit can be made possible when large scale investment in Moringa production in the near future. The established model value chain will be strengthened and become functional to export various products as large scale investors enter into the value chain. This will be best facilitated when production and processing technologies are introduced in the entire value chain.

The project activities and methodological approach

The project was designed to commercialize Moringa production. It was designed based on the understanding that under utilization of Moringa is resulted from limited awareness on its importance. Such limited or no awareness among both in rural and urban communities has remained for long an attributable factor for non-existence of market for *Moringa* as well as absence of its value chain in general. Farmers were not interested to grow Moringa tree because in the first place they were not aware of the importance of Moringa, secondly, if there was any aware famer, there was no market that may motivate him/her to grow *Moringa*.

By taking the prevailing ground reality, the project was implemented to create awareness among the different segment of the society, to promote and develop production, processing and marketing system for Moringa. In so doing, the enormous potential of Moringa will be realized. The working assumption adopted to guide implementation of the project was that creating demand/market for Moringa among urban residents and provide an incentive to farmers to grow Moringa. The other important assumption/principle adopted was that commercialization of Moringa would take place at a higher speed if a value chain approach is employed with a particular emphasis on linking rural producers with urban consumers. The major methodological elements of the entire approach of the project are described below.

Establishing model value chain strategic approach to commercialization of Moringa

Value chain approach has significant importance for commercialization of non-traded commodities (Jones and Shaikh, 2003). Commercialization of Moringa was made possible by applying a value chain approach. The approach identified three important stages; which are *production, processing, and consumption* stages. For a well functioning value chain, each of the three stages must be well interconnected to ensure sustainable supply and flow of value added product. It involved recruiting and training individual to play a defined role in the value chain. Under the project, a group of farmers was selected to play a producers role and continuously supply raw Moringa leaf to Moringa processors, which is the next stage in the model value chain. Women play a prominent role for well functioning of value chain, if they are integrated to various activities within the value chain (Alexandra, 2009). They were regularly monitored to ensure that they are playing their role as required. A group of women and unemployed youth were identified from the urban and peri-urban area and given intensive training on Moringa collection, drying methods, processing, packaging, and marketing with all precautionary safety measures to be considered in the process. The Moringa processing groups were regularly monitored by the project staff. The processing groups played the most important role in the value chain and served as a connecting bridge between producers and consumers. The third important stage in the value chain was the consumption stage. At this stage, the project identified two broader set of activities to be undertaken to facilitate the entire commercialization process. A serious of awareness creation activities were undertaken at different towns, for the case of this specific project, a serious of exhibition of various Moringa products were conducted by women groups. The exhibitions were conducted to serve a crucial objective of the project to create demand for Moringa products.

Demand Creation: Strategic Entry Point in Commercialization Process

After identifying the three stages, the critical challenge was where to start the intervention. Many projects failed when promoting commodities partly because they disregard the entire value chain, and rather focus only on part of the value chain (Jolly and Vijay, 1997). The very success of this project is attributed to the fact that the entire value chain was targeted. The entry point to develop the value chain as a strategic intervention was to create demand for Moringa products before embarking on distributing Moringa seedlings.

Two strategies were pursued to create demand for *Moringa* products. The first strategy was conducting a series of exhibition at different locations in urban areas. The urban areas selected for the exhibition are those areas where trader's movement between such areas and rural communities in Alamata woreda is very high. Accordingly, Alamata town itself and Mekele town were areas where series of exhibition were conducted to create demand among the residents of these towns.

The second strategy was use of mass media to create demand among wider communities particularly in Addis Ababa. More than 2000 leaflets were distributed in Addis Ababa and information was disseminated through Ethiopian television and radio because of which the demand for such *Moringa* product increased dramatically. The strategic purpose of selecting consumption stage as entry point was to create initial demand for *Moringa* product to create initial interest among farming communities to grow and produce *Moringa* on their farms. This was done with the assumption that farmers do not grow a commodity that does not have market demand.

The two strategies has created a substantial demand for *Moringa* products which inspired both farmers, female groups and other interested individuals to collect, process and supply *Moringa* product in response to the demand created. The growth trend of *Moringa* powder supply based on one sale point in Addis Ababa market is presented in Figure 1.

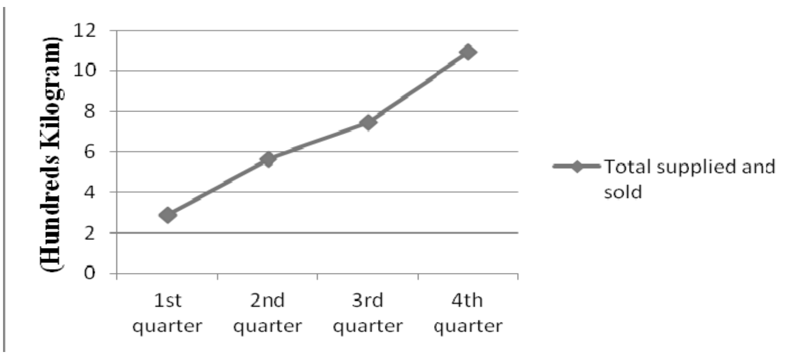

Figure 1. Moringa powder supply trend (2011 and 2012).

The women groups established at Alamata woreda are benefiting from the increasing demand by supplying continuously *Moringa* powder in Addis Ababa market. Their supply capacity was also growing at a higher rate. Their supply capacity increased during the last 4th quarter by 300%.

The need to integrate women as key value chain actors and success

The defining feature of cash crop production, which involves production of commodities for market, is that it entails engaging in output markets. This in turn depends on the ability to produce at scale, to achieve quality, and to secure low costs of transacting in markets (Vargas and Vigneri, 2011). Targeted women who were trained to produce *Moringa* powder were able to purchased fresh *Moringa* leaf from *Moringa* tree owners for wholesale and retail trade in a quantity that involves low cost and with the required quality. These female agents were relatively more mobile and were therefore able to connect to both rural communities (producers) and buyers in urban areas (consumption). This business model had substantial potential for rapid commercialization. The project targeted unemployed urban youth females and poor female residing in urban and peri-urban areas to engage in Moringa business. Their role as a linking agent between Moringa producers (rural) and consumer (urban) in the entire value chain was defined.

Hence, they were trained by the project on all aspects of *Moringa* powder preparation, packaging, and marketing. Integrating targeted women into the model value chain had involved rigorous task. Task of their integration was started by providing them intensive training on importance of *Moringa*, collection, processing and packaging as well as methods of advertising their product. They were also given training on safety measure to be applied when preparing *Moringa* powder. The targeted women were made aware of their role in the value chain to link rural production with urban consumption.

There were three reasons that justify the need to integrate women in the *Moringa* value chain through the project:

- Many of the tasks involved from collection up to delivery of final product to market are customarily roles of women. Many of these tasks are performed at home;
- Women are more efficient than men in preparation of *Moringa* products. As a result women could have produced more than double within given period of time and a lot of wastage of *Moringa* leaf was observed among men, which increased their cost of producing a kilogram of *Moringa*; and
- Women are disadvantage groups in every community, and by integrating them into *Moringa* value chain their economic status will be improved, hence contribute to reduce gender inequalities prevailing in the area.

Key elements of success factors in commercialization process

Regular value chain monitoring

The activities and progress of the women groups in particular the information dissemination process had to be regularly monitored to ensure that the model value chain is operating as desired. The whole activities of the women group as well as the supply of fresh and processed *Moringa* quality products have been monitored every 15 days. The regular monitoring activities had served the following purposes

- ensure/track expansion of demand for *Moringa* products through peer information exchange and various ways;
- ensure value chain actors who were trained on various aspect of Moringa are playing their defined role. These include ensuring hotel and cafeteria owners are serving Moringa tea, women groups are collecting, processing, packaging, and supplying Moringa powder continuously;
- ensure that support giving actors, such as Woreda Office of Agriculture, municipality, and other relevant institutions who took part in the project are playing their role;
- ensure the linkage between producers(*farmers who own Moringa trees*)-Processors (women groups who are trained to collect, process and market Moringa powder)-Consumers (*Urban residents*) is strengthened so that the demand and supply of *Moringa* products are expanding; and
- help identify gaps that need immediate correction measures or interventions and identify constraints that affect progress in the value chain development.

Proper documentation of available technologies and knowledge

Documenting important features of particularly underutilized and non-traded commodity that have potential economic value to the society is key factor of success in any commercialization process.

Continuous awareness creation for the available technologies

Awareness and demand creation is not a 'one go' practice particularly in interventions that aimed at commercializing underutilized and non-traded commodities. Awareness creation activities have to be continuously planned and executed depending on the result obtained from regular monitoring activities.

Using Value chain approach and empowering the whole value chain

Looking into and working through the entire value chain has been the key aspect of success in the *Moringa* commercialization process. The key aspect of establishing and empowering the whole value chain mainly focused on two aspects. The first is building the technical capacity of both chain and support actors. Chain actors' capacity includes technical capacity in *Moringa* processing, packaging and overall entrepreneurship skills for processors and *Moringa* tree management. The second aspect is creating wider demand for the product and linking with local and terminal markets by creating awareness/demand mainly among urban residents. To ensure sustainability of the demand created and ensure continuous supply of *Moringa* products, and ultimately to strengthen the *Moringa* value chain, the capacity of local value chain support actors drawn from different offices of the woreda were built through various mechanisms.

Alignment of both public and non-public development partners

The linkage and cooperation both in terms of building technical capacity and resources between public and non-public development actors is very crucial for *Moringa* commercialization. This alignment is critical to ensure sustainable production and supply of *Moringa* products as well as sustained and coordinated intervention to successful commercialization in a wider scale. Such partnership is also instrumental to ensure institutional support to commercialization process and scale-up successes achieved at microenterprise levels to nation-wide scale to move *Moringa* towards export sector.

Conclusions

- Value chain approach facilitates and speeds up commercialization of underutilized and non-traded commodities;
- Value chain approach enhances the benefits to the poor and women in rural and urban communities; and
- Apart from other methods such as leaflets, exhibitions and trainings, mass media should be intensively used in promoting underutilized agricultural or forestry commodities that can offer benefit to the society. Commercialization process is highly facilitated by use of mass media.

Recommendations

- As the model value chain will expand and link to various local and international markets, establishing a quality certification system is mandatory;
- The level of processing technology in use at present is very low, that the *Moringa* powder is being collected by hands, washed manually on big trays, sieved and dried on a clean bed sheet or canvases and converting it into powder using manually on wooden made grinder is very tiresome, that made mass

Moringa production through such process is impossible. Such process not supported by technology has made the whole process labor demanding and the constraining the possibility of mass production;

- It is crucial to reorient agricultural technology transfer strategies into the one that embrace value chain approach;
- Intervention aimed at promoting involvement of private investors is crucial for strengthening the model value chain established to further develop the chain from local to export market so as to earn foreign currency and promote *Moringa* as one of the contributor commodity for national economy;
- Production and distribution of *Moringa* seedlings has to be strengthened to consolidate the commercialization process;
- The experiences of other Asian and African countries have to be adopted particularly in processing and packaging aspects of *Moringa* products;
- Special program should be designed by regional agricultural bureaus to involve smallholder farmers and help them benefit from *Moringa* value chain. Their involvement can be both at production of *Moringa* and processing to supply at local market; and
- Commercialization process particularly the production of Moringa should not only be left for smallholder farmers, but require large-scale commercial farmers to sustainably supply the raw material for national and international market.

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The Contribution of Trichilia *emetica* for Energy and Food Security in Ethiopia

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Introduction

Trichilia emetica(Vahl.1790), T.roka (Forssk. Nom.nud), Chio (1923) nom. illegit is a medicinal tree species in the group of family Meliaceae. The genus *Trichilia* Browne (1756), nom conserves. Rochetia Delile (1846), Dewilde (1968) is a tropical genus of 85 species, most numerous in the new World, with 18 species in Africa and two in Asia. The Ethiopian *T. emetica* belongs to sub species *emetica* (Hedber and Edwards, 1989). Ecologically *T.emetica's* occurrence extends from Senegal to Uganda, Sudan, and Ethiopia, the Yemen and southwards to South Africa (Keay, 1989; Hedber and Edwards, 1989; Azene, 1993). It is a species of savanna woodland and the semi-humid lowland forests, frequently found in the moist parts along riverbanks at altitude 450-1700 m above sealevel. It prefers well-drained rich neutral pH soils and requires 600 to 2300 mm mean annual rainfall and 19 to 31^{o}c mean annual temperature. It tolerates frost, wind, termite, and salty soils (Azene, 1993; Thiraku, 1995). *T. emetica* is fast growing tree species reaching 15-30 m height, 70 cm diameter at breast height. Crown rounded to umbelliform, very dense and heavy dark evergreen foliage, with much branched, irregular, obliquely spreading branches. Bole straight, cylinderical, short, with low branching, sometimes divided into multistems. The bark is brownish grey, rough, deeply and longitudinally fissured. The leaf is compound, stalks and shoots soft hairy, leaf lets 2-5 pairs, subopposite, plus an odd terminal one, 8-10 pairs of parallel secondary nerves. Flowers are inconspicuous, fragrant clusters cream- green, 5 thick petals around a hairy center of stamens.

T. emetica is a tree that has been threatened because of the pressure exerted for its medicinal use. Before 1928, nearly 5000 metric tons of seed and 200 tons of oil were exported from Mozambique, but since then the trade has greatly declined. Africans of northern Nyasaland transported great quantities of *T. emetica* seed across the border to a soap factory at Kyela in Tanganyika. No current commercial use has been found for *T. emetica* in Ethiopia. The tree species is only known by general vegetation assessment (Azene, 1993;

Thirakul, 1995, personal observation). The socio-economic importance is totally forgotten and underutilized (Miftah and Temesgen, 2004). Accordingly, three forest areas in Ethiopia namely Delomena in Bale (Southeastern Ethiopia), Yayu in Illibabour (Southwestern Ethiopia) and Moyale in Borena (Southern Ethiopia) were assessed as it was expected for potential availability of *T.emetica*. Except, confusion of *T. emetica* with *T. dregeana* in Yayu forest, the real *T. emetica* was obtained only in Moyale. The objectives were to assess regeneration status to document indigenous knowledge on the species and to show its contribution for renewable energy and food security purposes.

Material and Methods

The study area

Moyale is located at $3^o68'$, $38^o61'$ and 1150 to 1350 m above sea level in Oromia Regional State, about 700 km from Addis Ababa. The landuse system shows that 9% of the land is arable, 60% pasture, 21% woodland and the remaining 10% is considered swampy, degraded, or otherwise unusable. Moyale district and Mega peasant association (PA) has no permanent rivers and known streams. It has sub-tropical (20%), and tropical (80%) agroclimatic zones. Basic soil types of the area are Lithosols, Calcaric and Eutric Regosols, Chromic and Pellic Vertisols. In 1997 census of Ethiopia Moyale had human populations 93669, with crude density 83 persons/km^2, cattle 138726, sheep 17707, goats 49001, equines 4027, and camels 36860. Commonly prevalent livestock disease includes trypanosomiasis, camel pox, black leg, anthrax and internal and external parasites (OPPD, 2000).

Data collection and analysis

Households (hh) were interviewed from August 2005 to May 2008. Within the limits of the forest where the species was occurring 30 hh (10 female and 20 male) that knew *T.emetica* (locally known as “Anona”) regardless of the hh head were randomly interviewed about the utilization and management of *T. emetica*. In Mega PA a transect line was laid to assess *T. emetica* regeneration. One quadrant plot (10 mx 10 m with 5 sub plots of 2 m x 2 m within the main plot) was systematically laid on the transect. Diameter at breast height (dbh), number of seedlings with dbh less than 4 cm and height less than 1.5 m, saplings with the range of dbh 4-8c m, poles and mature trees dbh >8 cm (Woldeselassie, 2001) were recorded from sample the plot along the transect established in the longest side of the forest. The social data were grouped to age and gender group and the regeneration data was categorized in to size classes using microsoft excel.

Results and Discussion

The local people divided the uses of *T.emetica* in to different parts, namely flower, leaf, fruit, bark, wood, and root. However, the knowledge behind different household varies with age group and gender. As given in Table 1, all parts of *T. emetica* from flower to root are useful for varies local uses such as food from fruit pulp, medicinal value from different parts.

The study showed that many of the interviewed people donot know the specific uses of the different organs of the species. In the sampled populations, only 50% of female and 45% of males know the uses of the species. All the interviewed people know the shade value of the tree, as the tree is the shadiest tree in the woodland. The people categorized in the age group above 38 are relatively more acquainted with the uses of the tree (Figure 3). From the tree part, the root and bark are more valuable for local medicine providing 8 and 6 different uses respectively (Table 1 and Figure 3).

From interviewee, nearly 73% of the respondents (22 persons) do not know the medicinal value of flowers. The females are more knowledgeable about the medicinal value of bark and root while the males are more about the seed of the tree. The cosmetic and food value of the oil from the seed was mostly used by old people and now a day the availability of modern materials limited its utilization. Moreover, the scarce availability of the species in the woodlands also limited the utilization of the species for its non- replaceable medicinal benefits obtained from the white and sandy honey of its flowering season. The leaf of *T.emetica* that is used as constant supply of fodder and medicine is a good opportunity and income source for the pastoral communities that are inaccessible to modern medicines. The local people that knew the medicinal value of leaves of *T.emetica* collect and sell to other pastoralists. The wood is also serving the usual benefit as firewood; it provides attractive smell to the house and to the people who are burning it. Although they have great interest to grow and conserve this tree species, they donot know how to plant and manage and it is hardly possible to get planting materials.

Table 1. The response of household members about *Trichilia emetica's* different part uses.

Gender	Age group (Years)	TNo of respondents	Flower		Fruit and seed		Leaf		Bark		Wood	Root		
			No. of respondents	Use**	No. of respondents	Use**	No. of respondents	Use**	No. of respondents	Use**	No. of respondents	Use**	No. of respondents	Use**
Female	18-28	3	1	A	1	E	2	J	3	Q+R	3	T+U	2	Q+R
	28-38	4	4	A+ B	2	D+E	3	J+K+L+M	4	N+O+P+Q+ R+S	4	T+U	3	N+O+P+Q+R+ S +V+W
	>38	3	1	C	3	D+E+F+H+I	3	J+K+L+M	3	N+O+P+Q+ R+S	3	T+U	3	N+O+P+Q+R+ S +V+W
Male	18-28	7	No	Do not know	3	E+F+H	4	J+K+L	7	Q+R	7	T+U	6	Q+R+ W
	28-38	9	7	A+ C	7	E+G+H	3	J+K+L	9	P+Q+R	9	T+U	9	P+Q+R +V+W
	>38	4	3	A+ B + C	3	D+E+F+G+ H+I	3	J+K+L+M	4	N+O+P+Q+ R+S	4	T+U	4	N+O+P+Q+R+ S+V+W

***List of uses of different parts of T. emetic*

A= Sources of honey
B=Solving eye pain
C=the honey obtained from the flower is used for solving problems of muscle, reduce labour during child delivery, and solves problem of cold and coughing
D=Solves muscular problems
E=Produces edible pulp
F=Produces soap and candle making oil
G=Produces wood oil
H=Produces cosmetic oil
I=Produces medicinal oil that used for diaharria
J=Used as fodder for goat and camel
K=Used to remove goat ascarries
L=Used as antimalaria
M=Prevents bleeding after delivery
N=Prevents irregularity of menstruation in women
O=Solves problem of sterility in women
P=Controls venereal diseases
Q=Prevents snake venom
R=Prevents tse tse fly and trypanasomiasis
S=Controls pain after delivery in livestocks and humans
T=Smoked for attractive smell after bathing before the invention of perfume
U= Source of construction material, furniture and charcoal making
V=Facilitate food digestion
W=Controls intestinal worms in human and livestocks

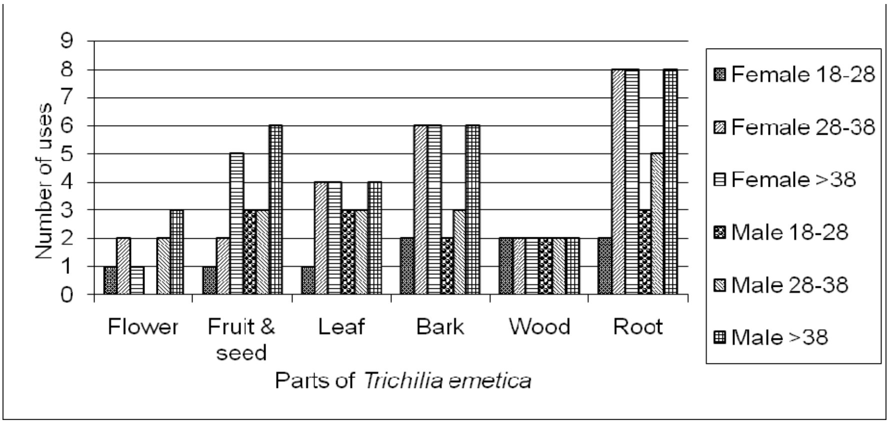

Figure 3. The number of uses of *T. emetica* organs known by gender and age group

The regeneration status was observed only in the remote part of the woodlands of Moyale. Only one sample plot was obtained within 10 km long transect. The local forest guardes who showed the species in the woodland responded that the species was extremely exploited for the various benefits mainly for previously used medicinal purpose. It was observed only at 700 m altitude above sea level and occupied in a patch within 100 km^2 (Table 2). In the study area, no information is available in forest department about the species.

Table 2. Regenerations of *T. emetica* at dbh classes

Scientific name	Family	DBH<4 cm	DBH 4-8cm	DBH> 8 cm	No. trees/ha
Trichilia emetic	Meliaceae	2	3	10	1500

Regeneration assessment revealed the availability of more matured trees as compared to seedlings, in the ratio of 1: 1.5: 5 seedlings: saplings: matured trees, respectively, probabily due to poor seed bank (Table 2) and recalcitrant nature of the seed. The number of trees accordingly could be 200, 300 and 1000 sedlings, saplings and matured trees, respectively. Moreover, it was observed in valley bottom that the species uses the shade of other plants for its seedling early survival. This might have indicated that habitat change and exploitation may facilitate it to be endangred. In Ethiopia, this species now days can be considered as an endagereded since it occurs only in Moyale with few number of individuals and series lack of regeneration. However, personal observation made during another forest inventory revealed its occurrence in south Omo, Ethiopia. To date no research or development activity has been conducted on this species in Ethiopia. Therefore, human intervention for the conservation and rational utilization of this species is highly important.

The Potential of *T. emetica*

Oil production potential as energy source

The seeds of *T.emetica* contain oil concentration as high as most oil rich dicotyledonous seeds. The oil produced is in the group of Oleum Theobromatis that include *Madhuca longifolia*, *Theobroma cacao*, and *Vitellaria paradoxa*. Oil is extracted from the seed pulp that is used for food and from the harder seed core (kernel) which is used in the preparation of soap. The oil resembles cacao butter, which can be obtained by boiling the seeds in water. It is yellow, not as soft as tallow, is mild in taste, and has the odor of cacao butter. It fuses at 42°C. OLEIN and PALMITIN are its constituents and when saponified it yields a large amount of palmitic acid *(*Miftah and Temesgen, 2004*)*. The oil used to make candle and can serve as source of biodiesel. It is excellent for commercial soap and cosmetics making oils (Azene *et al.,* 1993; Henry and Grindley 1994; Ruffo *et al.,* 2002).The oil produces a good finish on wooden surfaces and would compete successfully with other commercial wood oil (Grundy, 1993). However, silvicultural research and training on modern methods on how to extract oil from the seed deemed important for domestic use by the rural societies.

Fuel wood value

The wood is used for producing expensive and pleasant firewood and charcoal. Therefore, the wood can be used in domestic and commercial purpose to generate enegry at kitchen and factory. The wood is light with density of 560-597 Kg/m^3 at 15% moisture content, pinkish-grey which is also used for construction, tool handles, boats and standard plywood (Tack, 1953), making pestles and wooden plates, bowls and spoons. Artists use the attractive light-coloured wood for carvings and it is suitable for furniture making.

Food provision role

Processing seeds of *T.emetica* yields cooking oil, edible pulp, residual and fresh sauce or milk that could be used in seasoning different foods such as cassava, vegetables, meat and fish, that could be sold and consumed locally. The seeds are squeezed in water and the resulting tasty fatty suspension is used for cooking (Ruffo, et al. 2002). Edible and non-toxic portion of *T.emetica* fruit contains fat, carbohydrate, Ca, Mg, Fe, K, Na, particularly, 3164 $\mu g\ g^{-1}$ Phosphorus and 17% protein. The seed oil contains 53% palmitic acid

(Lancelot *et al.,* 2002). *T. emetica* is a highly nutritive fruit tree particularly among rural communities in southern Ethiopia and Mozambique.

Cosmetic value

The oil is used for anointing bodies and hair. The perfume value is still practiced, in southern Ethiopia, especially in old people. Three people responded that burning a piece of wood from *T.emetica* is much better than buying perfume, as it provides the heat value in cold nights and the value of perfume.

Medicinal value

The oil extracted from the seed kernel is used to treat rheumatism, leprosy, and fractures. The seed oil is applied to sores, ringworms, other parasites, and skin diseases. The bark is a remedy for pneumonia and the roots are used to treat colds and as a purgative. A decoction of the roots is used to treat intestinal worms, rheumatism, colds, and persistent infertility and to induce labour in pregnant women (Ruffo *et al.,* 2002). The extracts of *T. emetica* have antiplasmodial activity (Tahir *et al.,* 1999) and have growth-inhibiting effects on common plant pathogenic fungi (Lovang and Wildt-Person, 1998). In a study, it is found that *T. emetica* is a rich source of limonoids (trichilins) and seco-limonoids with antifeedant activity. The extract from rootbark was highly active against *Trypanosoma brucei* rhodesiense whereas the antiplasmodial activity was 100-fold lower (0.04 µg/ml versus 3.91 µg/ml). It can be speculated that the tree can be remarkably selected for trypanosomes is due to the presence of limonoids (Freiburghaus *et al.,* 1996). Livestock disease is very common in Moyale and the medicinal importance of *T.emetica* is increasing due to inaccessibility of modern medicine. The people are frequently debarking *T. emetica* for medicinal purposes and there are some trees that are dried.

Environmental value

The tree is evergreen and makes the underneath shady and moist. So, it can be a good source of fuel wood in homegardens in agroforestry system. The promising coppicing ability offers a good shade in dry urban areas. Therefore, it is excellent for windbreaks for salty soils and water catchments rehabilitation in areas that experience slight frost (Grundy, 1993). Culturally it is believed that taking rest under the tree and making spritual prey brings luck as responded from the local people of the study area. Similar believes are reviewed from Tanzania.

Management requirements

Seed handling

Practically seeds of T.emetica are surrounded by hulls that are prone to mold infection thus making seed storage very difficult. Different studies revealed that the fruit has 3 to 4 parts and each part contains 1 or 2 bean like blackish red seed. If there is rain in April, seeds can be obtained in August and September in southern Ethiopia. The number of seed per kg is 1950. In a 4 kg of fruit about 1 kg seed is extracted. For seed to germinate requires the removal of seed aril. Since the seed is recalcitrant, sowing should be made within 3 days of collection. The seed germinates within 15-23 days and reaches plantable size seedling in 6 -8 months time (Miftah and Temesgen, 2004). However, there is a need to investigate the optimum storage conditions for seeds and to determine ways of dehulling the seeds to prolong their shelf life. In Kenya, fresh seeds at 39.6% moisture content (MC) germinated 100%. The germination capacity decreases to 50% following desiccation to 14.3% MC (Baxter *et al.,* 2005).

Plantation development

When raised from seed it can attain 5 m in height and 5 cm in diameter in 4 years. Since the tree is propagated by root sucker, the planting spacing is 3 m for timber production in monoculture plantation and 6 m for seed production and for agroforestry purpose. After 5 years of planting up to 60-80 years, the bark and root can be used for medicinal purposes (Miftah and Temesgen 2004; Matakal *et al.,* 2005). There are pests/ diseases that need identification and practical control measures.

Oil marketing and challenges for intervention

As any product creates its own demand, the supply of seedling and oil to public and possible tree grower and soap or candle manufacturer is believed to create attractive market once there is a sort of public show. The interviewee responded that they need planting material of *T.emetica*, the oil for medicinal purposes, as the cost of medicine in towns is very high. The tree species is located in very inaccessible places, and collection of planting material is very difficult. Even the collection of socio-economic and regeneration data for this paper was assisted by district polices and guards.

Conclusions and Recommendations

In Ethiopia *T. emetica* is unknowingly endagered because of habitate change and exploitation for medicinal purposes. It exists only in low land area of southern Ethiopia restricted to dry and moist Kolla agroclimatic zones namely Moyale and south Omo. The environmental values of *T. emetica* is quite significant for dry areas as it has evergreen leaves, water absorbing and shade bearing potential, and drought and frost tolerance capacity, inaddition to attractive stature, it is a candidate tree for aesthetic purposes, road side plantation, urban beautification and degraded land rehabilitation. In the ever-increasing demand for energy crop and medicinal plant, its oil is a good source of biodiesel and pharmaceutical raw material. Currently, since the local people are not aware of the utilization and conservation of the species, it resulted in it's over exploitation. Therefore, this species should be in the priority agenda of conservation of indigenous tree species in one hand and economic tree for the production of oil. The availability of industrial oils and soaps may reduce the interest of planting this tree species, however, the need for conserving the genetics of the species and the need for environmental stability in addition to subsistent income sources deserves plantation development of the species.

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Household Contribution of Bamboo in Masha District, Southern Ethiopia

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Introduction

Non Timber Forest Products (NTFP) are all the biological materials, products both from fauna and flora, (other than industrial round wood and derived sawn timber, woodchips, wood-based panels and pulp) that may be extracted from natural ecosystems, managed plantations, etc., and utilized within the household, be marketed or have social, cultural or religious significance (Ros-Tonen, 2000). Bamboo is one of the highest yielding renewable resource that has huge economic and development potential as an alternate "cash crop". The development of bamboo helps to solve problems of housing, furniture shortage and job opportunities (UNIDO, 2007). In Ethiopia there are two species of bamboo namely *Yushania alpina* (K. Schum) previously called *Arundinaria alpina* (K.Schum) and *Oxytenanthera abyssinica* (A. Rich) Munro (Hedberg and Edwards, 1989). Ethiopia has the largest share of bamboo source in Africa that accounts about 67% of the African bamboo resource (UNIDO, 2009).

Y. alpina ("Kerekeha" in local language) is a highland bamboo species growing in altitudes between 2,200 and 3,500 m a.s.l. *O. abyssinica* ("Shimel" local languages) is a lowland bamboo growing within altitude between 700 and 1,800 m a.s.l.. These bamboo species provide NTFPs and plays an important role as a supplement to satisfy ever-increasing demands of woody biomass materials. The scarcity of construction materials necessitated the use of bamboo for many purposes (Tesfaye, 2006).

In Ethiopia, many people have been using bamboo in their everyday life for thousands of years and still the most indispensable NTFPs for rural communities. It is one of the four noble plants in Ethiopia-together with *coffee* (Coffee species) "*enset*" (*Enset ventricosum*) and *eucalypts (Eucalyptus species)* (Tesfaye, 2006). In spite of its multiple use and environmental services, still bamboo is one of the most neglected natural resource in Ethiopia (Tesfaye, 2006). Bamboo has long been regarded as multipurpose plant in many palces where it has thousands uses ranging from food to house construction, mainly to replace many of the timber products traditionally derived from forest tree species (UNIDO, 2009). Domestic market for bamboo products like furniture, baskets, utensils, mats, beehives, house construction and others is quite substantial. For the poorer households, natural bamboo provides a safety net, especially through the open access condition for harvesting. However, lack of formal market and the poor quality affected the income amount (Haile, 2005). Within many households, manufacturing of bamboo products is something extra to increase the household income, next to the basic agriculture activities, which provide their basic income. Different studies showed that there are limited quantitative studies with regard to the contribution of bamboo to the rural household income, except general description of its use. Therefore, to make informed decision, it is important to study the household income contribution of bamboo and its comparative advantages with other NTFPs and other farming products. Accordingly, a household survey was conducted at Masha, one of the highland natural bamboo growing area, with the objective to quantify the household income and house construction role derived from bamboo, and to compare it with other farming products (crops and livestocks) of rural households and to investigate its major threats.

Materials and Methods

The study area

The study was conducted in three peasant associations (PA) situated at Masha district, Sheka zone of Southern Nations and Nationalities People Regional State (SNNPRS), Ethiopia. These were Gada, Yina and Yepo PA. Yepo PA located at 7º46'/ 35°34’, Yina PA at 7º38'/ 35°30’ and Gada PA at 7º38'/ 35º33'. The mean annual temperature of the studied area varies from 10°C at higher altitudes to 19°C at lower altitudes. The mean annual rainfall varies from 1100 mm to 2200 mm and the mean annual potential evapo transpiration (PET) varies from 1350 to 1500 mm, hence the length of the growing period (LGP) of the area is above 300 days per annum (MOA, 1998; ZCS, 1993; Annonmous, 2006). The dominant land use/ land cover in Yepo, Yina, and Gada PA were primary forest, bamboo, and enset. The details of which given in Senbeta (2006). The local people obtain different NTFPs like spices, mushrooms, bamboo etc from the forest. The Masha natural bamboo forest was stocked with 8840 trees ha^{-1}, where mean height is 16.8 m, and diameter is 7.6 cm (Kassahun *et. al*., 2004). The soils are made up of different taxonomic groups such as Nitosols, Orthic Acrisols and Chromic Luvisols (MOA, 1998). The total human population in Yepo, Yina, and Gada was 6400, 2310 and 1572, respectively, which are in 570, 385 and 259 households (DDA, 2005).

Data collection and analyses

In each peasant association, total household number, total human population and households that effectively practice the major farm activities were obtained from the district (woreda) agricultural and natural resources bureau (DDA, 2005). Farmers' households were stratified based on major mixed farming activities like livestock, annual agricultural crops, enset, NTFPs, coffee, and wood products and others doing none or one of these activities. From the major practitioners of mixed farming activities, in Yepo, Yina, and Gada PA, 15, 7 and 10 HHs, respectively were randomly interviewed about the uses of bamboo in comparison with food crops, livestocks, wood products, and other NTFPs. The threats to the existing bamboo forest were observed and interviewed to officials in forest department.

The cost data of farming activities was based on the cultivation, and management activities of food crops and livestocks in one hand, and the collection and transport of activities of wood and NTFPs. The income data considered was selling at farmgate prices of 2007. A 25 years data was predicted first and then discounted at 3% interest rate [equation 1] as used by national bank of Ethiopia for cash deposit. In traditional grass house construction, the quantity of bamboo, wood, and climber required was obtained by samplig three newly built houses in each PA. In each PA, house sizes were measured by local units called feet (1 foot equals about 0.3048 m). Usually 8-15 feet radius houses are built in the district. The volume of wood used in construction was calculated by common volume formula (Philip, 1994). The quantity of climber required was determined by adult man or woman load (pack). The volume of bamboo required was calculated by volume formula [equation 2]. The wood components of local house are single and thick central support "Miseso", wall "gidgida", and rings of walls "gigida mager". All cost and incomes were in Ethiopian Birr (ETB). The cylinderical correction factor or form factor was determined after felling stems (Philip, 1994).

$$\textbf{Net income at NPV terms} = (Bo - Co) + \sum_{t=1}^{n} \frac{[(B-C)_n]}{[(1+i)^n]}$$ [Equation 1]

Volume of bamboo= $\pi/4(dbh^2)*ff*H$ [Equation 2]

Where, dbh= diameter at breast height, H=total height above the ground, ff=form factor.

Results and Discussion

Income share of NTFPs in mixed farming products

The household income from NTFPs and other farming activities were summarized in Table 1. The major farming activities based on descending order of their importance are enset products, annual agricultural products such as wheat, and barely, livestock products, NTFPs, Wood products or (Timber Forest Products) and Coffee. From the farming products, the contribution of enset (*Enset ventricosum*) was the highest. However, Table 1 showed that a most important product might not necessarily have a highest contribution to the household income. The major NTFPs encountered in the present study were bamboo, spices such as cardamom, climbers, honey, medicinal plants, and mushroom. NTFPs was found to be the third income earning product in Gada PA, the second in Yepo, and the third in Yina PA (Table 1). Other studies such as Haile (2005) stated the richness of area by NTFPs, containing over 500 different NTFPs. Most of these are only used locally, but some including bamboo have regional and even international markets. The result of this study also indicated that honey production and bamboo are the two main sources of income from NTFPs in all PAs. Yepo PA is well known for the production of honey in the country level.

Table 1. Household income contribution of farming products

PA	Annual agricultural product (%)	Coffee product (%)	NTFPs (%)	Enset product (%)	Wood products or (Timber Forest Product) (%)	Livestock product (%)
Gada	0.5	1.9	12.9	65.2	14.7	4.8
Yepo	3.4	12.3	27.3	41.9	11.2	3.9
Yina	5.5	0.0	9.1	68.1	9.6	7.7

The honey besides serving as HH income it is used for food, making local drink, medicine, and ingredients for other foodstuffs. In Yepo PA the availability of bamboo is lower as compared to the other two PAs and most of the bamboo demanding activities is satisfied by purchasing from nearby markets at Yina and Gada PA. The contribution of honey to NTFPs income of households was 82.9%, 92.1% and 69.9%, while that of bamboo was 16.3, 0.7% and 28.1%, respectively in the Gada, Yepo and Yina PA (Table 2). Although the net income obtained from honey is higher than bamboo, all households use bamboo at least for one household activity such as fencing or housing, but there are households that does not use honey.

Table 2. Household income contribution of NTFPs

Peasant association	Type of NTFP	Net income (profit) (%)
Gada	Bamboo	16.3
	Climbers for house construction	0.2
	Honey from bamboo hive	82.9
	Medicinal plants	0.7
Yepo	Bamboo	0.7
	Cardamom (from natural forest)	6.2
	Climbers	0.4
	Honey	92.1
	Medicinal plants	0.3
	Mushroom	0.2
Yina	Bamboo	28.1
	Climbers	0.7
	Honey	69.9
	Medicinal plants	0.2
	Mushroom	1.1

Mushrooms and bamboo are also used as food; however, their contribution is relatively small because they are rarely growing and not readily available throughout the year. Bamboo shoots are available mainly in April or May and mushroom is available in September to October (personal communication with local farmers). In Gada PA the highest approximate mean net-income of bamboo shoots recorded at household level were 2652 Birr (Table 3). These NTPFs are cooked with vegetable to make the locally called “wot” and served with “enjera,” bread, or “kotcho” (local bread from enset).

Household income of bamboo

Bamboo in households has multiple uses, for example, it is used to produce honeybee hive, spices container, and fence, and used to make a sharp tool for processing enset products (serve as knife). Bamboo has diverse benefits and its being part of many of the household utensils and components of materials.Undergrowth vegetation and mushrooms are excellently grown under the natural bamboo forest. Local people earn money by selling bamboo stems brought from the forest, table and basket made from bamboo. As can be seen from Table 3 most of the bamboo is used for construction and beehive making.

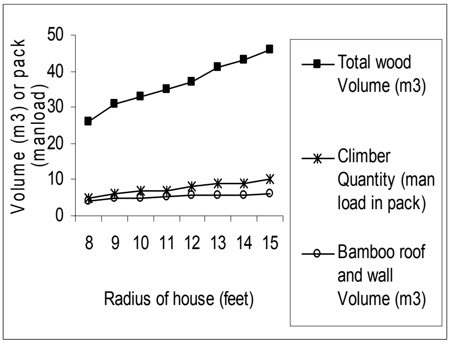
Table 3. Household cost and income distribution of bamboo.

Peasant association	Uses of bamboo	NPV (net income)	NPV (Cost)	NPV (Income)
Gada	Bamboo -fencing	721	1445	2166
	Bamboo -house construction	55	22	77
	Bamboo hive and container making	648	248	896
	Bamboo shoot	2652	165	2817
Yepo	Bamboo for fencing	4	2	6
	Bamboo for house construction	355	169	524
Yina	Bamboo for fencing	264	241	505
	Bamboo for fire wood	2545	644	3189
	Bamboo shoot for food	1671	677	2348
	Bamboo for house construction	104	106	210
	Bamboo sheath as cover hive and house	296	427	723

Construction role of bamboo

The local people in the three PAs have similar experience towards the uses of bamboo. Usually, bamboo is used for house construction, fencing, local grain storehouse “Gotera”, honey bee hive making and cover of hive (bamboo sheath). The fences from bamboo are used up to 10 years in cold areas like Yina PA and up to 2 years in relatively warm areas like Yepo PA. Houses constructed by bamboo are serving upto 30 years in cold areas of Gada, 20 years at Yina PA and 15 years at Yepo PA (Personal communication). In all PAs bamboo is used for construction of roofs and walls of houses. Moreover, in Yina and Gada where bamboo is available in abundance quantity more number of bamboo stems are used. Bigger solid stems of bamboo >7 cm diameter (dbh) and 15-20 m height are used usually for fencing and smaller solid stems of bamboo nearly 6 cm dbh and 10-13 m length are used for house construction. The average form factor was calculated as 0.45 (data not given).

The rural bamboo roofed house as shown in Figure. 4 is constructed additionally from wood, and climbers. The climbers are serving to fasten the bamboo together. Usually the climbers are sold in the market as pack measured in man or woman load. On average, a man or woman load is 36 kg. The size of local house is measure in feet that is nearly equivalent to 0.3048 m. The measurement is done from the radius that centres around the central pillar localy called “MisesoThe amount of the three components used in peasant association. The average life spans of houses and contracting new ones various from PA to PA. In Yina PA the average life of houses is 20years, in Yepo PA 15 years and in Gada PA it is up to 30 years.



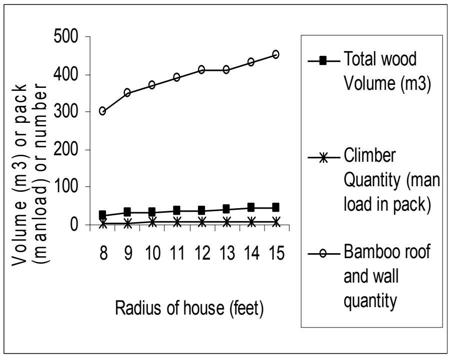
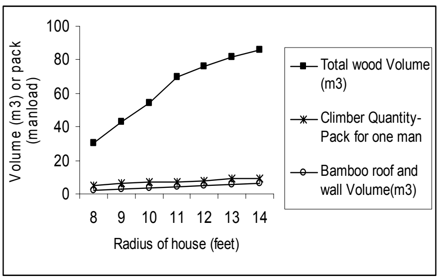


Figure 1a (left). Volume of bamboo used as component for house construction at Yina PA
Figure 1b (right). Quantity of bamboo used as component for house construction at Yina PA

The volume of bamboo required to construct rural traditional house accounts 13-16% of the wood volume in Yina, 6-8% in Yepo, and 9-11% in Gada PA (figure 1a, 2a and 3a). In 8-14 feet radius house construction, 4.1-5.82 m^3 volume of bamboo in Yina, 2.4 -6 m^3 in Yepo, and 3.1-4.3m^3 in Gada are exploited from the bamboo forest at intervals of 20, 15 and 30 years by each household respectively. However, the number of bamboo stems used to construct house ranges from 300-430 in Yina, 120-300 in Yepo and 306-434 in Gada PA respectively for 8 - 15 feet radius house (Figure. 1b, 2b and 3b).



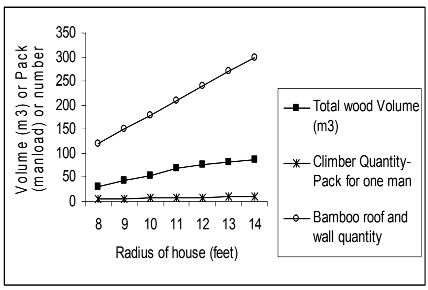
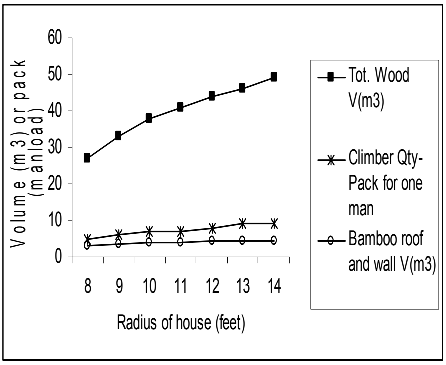


Figure 2a (left). Volume of bamboo used as component for house construction at Yepo PA
Figure 2b (right). Quantity of bamboo used as component for house construction at Yepo PA



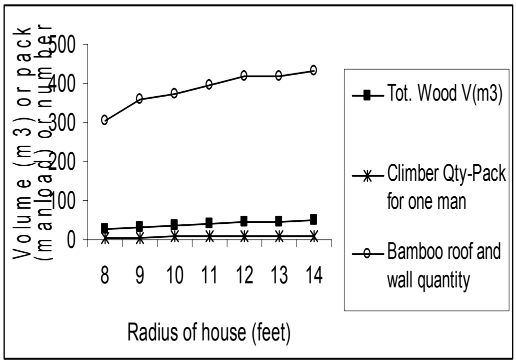


Figure 3a (left). Volume of bamboo used as component for house construction at Gada PA.
Figure 3b (right). Quantity of bamboo used as component for house construction at Gada PA.

Major threats of bamboo at Masha-Sheka zone

There are different types of threats that are damaging the existence of Masha bamboo forest in addition to the natural death created by gregarious flowering.

Encroachment by local people

The bamboo forest at Masha is easily accessible to local people and traders travelling from Tepi to Masha towns. There are a number of residents inside and close to the forest. Accordingly, the encroachment rate is very high. Illegal cutting and inapropriate harvesting techniques damaged the population of bamboo significantly. Higher proportions of stems are damaged as compared to those utilized. People occasionally travelling around the forest, for example, during market days, are randomly cutting bamboo stems. The illegal cutting was very difficult to be controlled because the forest area was too wide for few guards. Other complimentary measured should have to be in place such as constructing a fence especially along the borders of public road. Similarly, the local residents and communities need to take responsibility in managing and utilizing the forest (personal communication with forest guards).

Lack of regeneration

There is no management plan for bamboo forests of Masha. The stocking is not uniform, in some places, it is highly dense, and in other, it is scattered. Overstocking, over maturity, old age and the resulting mass flowering are resulting in falling and death of many bamboo stems. No promising regeneration and no appropriate gaps created for regeneration. The felling of stems is very haphazard and there is selective cutting. Management approaches are suggested to improve the productivity and product quality of the remnant bamboo forest of Masha, based on diagnostic information (Kassahun, 2003). However, this recommendation was not put into practice. The people interviewed responded that getting bamboo shoot and regeneration of other woody plant species some ten years ago was much better than today. The lack of bamboo shoot today could probably attribute to climate change and haphazardness of cutting of bamboo population.

Expansion of grass land

The bamboo forest is adjoined with marshy grassland. Probably because of climate change and frequent disturbance by nearby grazing, lack of proper diversion of seasonal water flow, the grassland is expanding towards to the bamboo forest. Stems dried some bamboo due to water logging. This requires proper drainage (personal observation).

Expansion of agricultural land and settlement

There are many settlers and new immigrates to the bamboo forest. Although there are some control measures over the expansion of agricultural land, there is a slight move to the forest by the local settlers. Moreover, the settlers are selectively cutting for firewood and fencing. No enrichment planting was observed in the studied peasant association. The residents are not willing to plant bamboo, because of the availability of natural stands of bamboo. Investors are interested to clear bamboo and want to plant other monoculture plantation such as coffee and/or tea. The local people would like to plant eucalyptus and investors want to plant tea in the highland and coffee lowlands. The possible way seemingly to halt devastation of bamboo stands is prohibiting settlement close to the natural bamboo stands. The natural stand also requires management plan on annual and seasonal cutting of the forest and clearing of bamboo is devastating. Investors should be initiated on the proper utilization of bamboo through wise processing and value additions to its various products.

Inefficient utilization of bamboo stems

The cutting from natural stands as well as the utilization of bamboo stems is wasteful. To cut a single stem, 4 to 6 other stems are usually broken in the forest stand. Similarly, to cut a 1 m long bamboo stems a 4 m stems are cut and left unused. This is because of lack of knowledge on using bamboo and due to the lack of managerial ownership. There are few activities undergoing by different Non Governmental Organizations in training the utilization of bamboo (personal communication). Such activities should be strengthening to bring the ownership and sustainable management and utilization. Therefore, training on the utilization and security of ownership are highly important.

Measures to develop bamboo resources have been taken by East Africa bamboo project mainly in Ethiopia and Kenya aimed at promoting the development of sustainable production of bamboo in East African countries with focus on marketing (UNIDO, 2006). The project has included only three bamboo-growing areas namely Asosa, Injibara, and Hagere Selam.

Conclusions and Recommendations

The uses of bamboo to the Gada and Yina peasant association of Masha Sheka zone are non- replaceable within the mixed farming system. Income, food value, employment, and local house construction uses are the main benefits that urge the conservation of the bamboo forestland. The bamboo forest is declining both by natural and manmade threats. This resource is being significantly degraded because of expansion for tea and coffee plantation. Therefore, the local government and forest department of the area should put collective efforts to save the devastation of bamboo forest. Preparation and practicing of management plan of the bamboo forest, establishment of propagation site and enrichment planting, training on management and utilization are crucial activities that should be done in the bamboo forest of Masha Sheka zone.

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Selection of Tree/ Shrub Species for Biomass Based Energy Production

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Introduction

At present more than 90% of the domestic supplies of industrial wood and firewood comes from the natural forests which are the main sources of wood products. Fuel wood accounts for the bulk of the wood used, and is the predominantly preferred domestic fuel in both rural and urban areas.

The projected demand for fuel wood and building poles based on assumed per capita requirement is on the increase and is expected to be over 100 million m^3 by 2020. On the other hand, the projected supply from all sources is expected to be only nine million m^3 which is far below the demand (Country Report Ethiopia, 2012).

This deficit is among the main causes of deforestation of the Ethiopia's forest resource base. As the result, resources in some parts of the country reached irreversible stage and hence household economy is reducing greatly. One alternative of filling the deficit of fuel wood is to establish fuel wood plantations. But there are two problems. The first is the availability of land for establishment of fuel wood plantations near the cities and towns where fuel wood shortage is critical. The second is insufficient knowledge of fast growing species and ability of producing high woody biomass within short rotation periods.

To solve these problems, biomass can be produced where land is available and using technologies such as high conversion efficiency, energy saving and briquetting where the biomass transport cost can be reduced. To fill the knowledge gap of fast growing species and capable of producing high woody biomass within short rotation, selection of the species was proposed. The objective of this study was to select species which have the ability of producing high woody biomass within short rotation with high calorific value for fuel wood.

Materials and Methods

Study site

The study site was at Wondo Genet College of Forestry. The site is located some 260 km south of the capital, Addis Ababa. According to Eriksson and Stern (1987), the area has a tropical wet-dry or highland climate and the soil are volcanic. The annual rainfall is 1200 mm but it varies between 700-1400 mm. The mean temperature throughout the year is about 19^0c.

Studied species

Cassia didymobotrya: It is an indigenous species of Ethiopia (Azene Brkele, 1993). It is a bush, evergreen and distributed in the three agroclimatic zones of Ethiopia. It reaches up to 5 m in height. It is used for fuel wood, medicine and soil conservation.

Vernonia amygdalina:It is an indigenous woody shrub or small tree of 2- 5 m with petiolate leaf of about 6 mm diameter and elliptic shape. The leaves are green with a characteristic odour and a bitter taste distributed in the three agroclimatic zones of Ethiopia. It is used for charcoal, firewood fodder, soil improvement and medicine (ICRF, 1994).

Justicia schimperiana:It is a common shrub and distributed in the three agroclimatic zones. It is used firewood and life fence (ICRF, 1994.)

Buddleja polystachya: It is a small tree or shrub. It is found from 1,000 – 3,000 m a.s.l. It is used for fuel wood, fodder, bee forage, life fence and medicine (Reinhard and Admasu, 1994).

Expermental design

The research design was randomized complete block deign (RCBD) for screening of the species for woody biomass production. There were four species, namely *Vernonia amygdalina*, *Cassia didymobotrya*, *Justicia schimperiana and Buddleja polystachya* with five replications. Each treatment had 49 plants per plot. The spacing among the plants and plots were 1 m and 3 m, respectively. The distance between the blocks was 5 m. The size of the plot was 49 m^2. For calorific value test, CRD design was employed with five replications and tested using bomb calorimeter at air-dry basis for all treated species.

Data collection and analysis

The central 25 plants of each plot were the sample plants. Each sample plants was cut and biomass measurement was taken at the end of the 3rd year in kg at oven-dry basis. Samples for calorific value test were taken from main stem and branch at air-dry base for all treated species. Biomass production and calorific value data were subjected to ANOVA using statistical package SAS.

Results

Biomass production

Table 1. The table shows the ANOVA results of biomass production.

Source	DF	SS	Mean biomass (kg)	F- Value	Pr > F
Block	4	21.93	5.48	0.18[NS]	0.9504[NS]
Trees/Shrubs	3	5758.2	1919.40	61.82**	<0.0001
Error	466	14468.78	31.05		
Total	473	20234.61			

*NS-Not significant; **- Highly Significant.*

Calorific Value

Table 2. The table shows the ANOVA results of calorific value

Source	DF	SS	Mean Calorific Value **(MJ/kg)**	F- Value	F- Value
Trees/Shrubs	3	36.22	12.07487500	189.83 **	<. 0001
Error	16	1.02	0.06360938		
Total	19	37.24			

***: Highly Significant.*

Table 3. The table shows the Mean Dbh, H, survival and Biomass

Studied Species	Mean survival (%)	Mean Dbh (cm)	Mean H(m)	Mean Biomass (Kg/ha)
Buddleja polystachya	96.8	4.25	9.8	1421.70
Vernonia amygdalina	85.2	2.9	5.34	683.84
Cassia didymobotrya	92.7	1.86	3.71	170.11
Justicia schimperiana	94.4	1.67	2.92	145.76

***Dbh** - Diameter at breast height; **H** – Height; **Kg/ha** - kilogram per hectare.*

Discussion

Biomass production

The ANOVA results of the biomass (Table 1) at alpha 0.05, suggested that there is a highly significant difference among the treatment levels. R-Square is 0.86% and coefficient variation is 20.09. The mean separation on biomass production at alpha 0.05 was analyzed using Duncan's Multiple Range Test (Table 1).

Table 4. Duncan's Multiple Range Test for Biomass
Alpha=0.05

Species	Mean of biomass (kg)	Number of samples
Buddleja polystachya	17.77 [a]	121
Vernonia amygdalina	8.55[b]	119
Cassia didymobotrya	2.13[c]	116
Justicia schimperiana	1.82 [c]	118

Note: Means with the same letter are not significantly different.

The Duncan's Multiple Range Test for Biomass showed that *Buddleja polystachya* with a mean of 17.77 kg or 1421.696 kg/ha is the best of all treated species (Table 3 and 4).

Calorific value

The ANOVA results of the Calorific value (Table 2) at alpha 0.05, suggested that there is a highly significant difference among the treatment levels. R-Square is 0.97 and coefficient variation is 1.46. The mean separation on calorific value at alpha 0.05 was analyzed using Duncan's Multiple Range Test (Table 5).

Table 5 . Duncan's Multiple Range Test for Calorific value

Alpha = 0.05

Species	Mean of calorific value (MJ/kg)	Number of samples
Vernonia amygdalina	18.74 [A]	5
Buddleja polystachya	18.55[A]	5
Cassia didymobotrya	16.11 [B]	5
Justicia schimperiana	15.82[B]	5

Note: Means with the same letter are not significantly different.

The Duncan's Multiple Range Test for Calorific value showed that *Vernonia amygdalina* and *Buddleja polystachya* have no significant deference. But they are superior to *Cassiadidymobotrya* and *Justicia schimperiana* (Table 5).

Conculisons and Recommendations

Biomass production of *Buddleja polystachya* was 17.77 kg where as *Vernonia amyggdalina* was 8.55 kg. Since the calorific value of both species has no significant difference, *Buddleja polystachya* is the best for woody biomass production within short rotation compared to the other studied species.

The use of renewable source of energy as fuel instead of coal or oil (expensive) is advantages. In conclusion, *Buddleja polystachya* can be used for the production of biomass for fuel wood and using briquetting technologywhere briqutte can be transported cheaply.

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The Socio-Economic Contribution of Bamboo

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Introduction

Bamboo is becoming so increasingly important in the world's forest economy, because 1) it is a superior wood substitute, 2) it is cheap and efficient, 3) it is environmentally friendly i.e. it has high potential for environmental protection and wide ecological adaptation 4) the world forest is shrinking. Besides their economic contributions, the fact that their use is ecologically less destructive compared to harvesting of timber, sporadic agriculture and livestock rearing have encouraged the belief that more intensive management of woodland forests for such products could contribute to both development options and conservation objectives, and have led to initiatives to expand commercial use of NTFPs in various arid and semi-arid regions of Africa (Mulugeta and Demel, 2004).

According to Zhaohua (2001) over 1500 distinct uses of bamboo have been recorded; the number is also growing rapidly with new development initiatives in the world. Different bamboo products that are excellent substitutes for timber-produced materials have been innovated. For example, bamboo floorboards, fabricated panels, handicrafts, bamboo curtains (window blinds), and sophisticated ceilings, charcoal, paper, medicine, edible bamboo shoots, clothes, bio-energy, bamboo beer, bamboo soft drinks, etc. are important bamboo products in China. Bamboo pipe-lines (more than 150 km) in Tanzania (Kigomo, 1988), bamboo housing in Costa Rica and other parts of Latin America, mat boards in India, composite panels such as oriented strand board particleboard, fiberboard, and laminated bamboo composite in different countries (Lee *et al.,* 1996; Naresworo and Naoto, 2000; Jamaludin *et al.,* 2001; Lee and Liu, 2003) are worth mentioning. Eco-tourism value of bamboo is also high.

Globally, 1 billion people live in bamboo houses; the economy of 2.5 billion people comes from bamboo. Annual trade earns 5-7 billion USD from bamboo (tropical timber earns 8 billion USD). Additionally, bamboo is an evergreen forest that grows fast; and gives high biomass. Several bamboo species tolerate and perform well in cold climates whereas others are not doing so. Development of the bamboo sector in China helped to increase the income of local farmers, and improve the rural environment and sustainable development of country's economy (*e.g.* average increase of income per household per year in Anji county of Hangzou province is 6,250 RMB which is 45.12 % of the total income of a household in 2002 (Zhaohua 2004).

Ethiopia is one of the most endowed countries in bamboo resources. According to Embaye (2000), the area coverage of natural bamboo forest of the country is about 1 million ha, which is about 7% of the world total and 67% of the African bamboo forest area. The two indigenous bamboo species in the country are the African alpine bamboo (*Yushania alpina*) K.Schumann Lin (a monopodial/leptomorphic rhizome bamboo) and a monotypic genus of lowland bamboo (*Oxytenanthera abyssinica* (A. Rich) Munro (a sympodial bamboo/having pachymorphic rhizome) (Embaye, 2004; Bekele, 1993; Hedberg and Edwards, 1995; Ohrnberger, 1999). However, unlike other countries the development and utilization of bamboo is not exploited. Unfortunately, in the country, the bamboo sector is not officially encouraged to date. Development packages do not include bamboo at all (Tessema, 2000). Moreover, currently, there is indiscriminate forest loose and depletion hence the unique bamboo resource will be disappearing before its economical and environmental advantage is appreciated, unless important reversing mechanisms could not take place. Currently, its use is by far below its potential. It has been customary and mainly limited to hut construction, fencing and to a lesser extent production of handicrafts, furniture, containers for water transport, and storage, baskets, beehive, fences, firewood, fodder, house utensils, and various art-facts, walking sticks (Embaye, 2004). It's potential in substituting industrial wood hence potential of narrowing down the gap between the demand and supply is not recognized. Whereas, the current demand for industrial wood in the country is 400,000 m^3 yr^{-1} of which sawn wood accounts for 85 percent. Annual incremental yield from industrial plantation available as saw log is estimated to be between 150,000 to 200,000 m^3 yr^{-1}, while consumption is in excess of 200,000 m^3 yr^{-1} (FAO, 2002). Demand for the consumption of lumber and wood-based products in the country is expected to increase in the future. Currently there is acute shortage of forest products in the country and on per annual basis; the wood demand is more than thrice than supply from all natural and plantation forests.

Sound development of these commodities however; require a good understanding of the socio-economic contribution of this sub sector to local, regional and national economy at large. Information on producers perception, production and export constraints, trade requirements from importing countries, trade and marketing channels, effect of transboundary issues, policy issues (land use) such as conflict of interests, and quality and standard issues which are impediments to sound development of the sub-sector are either fragmented or totally lacking at national level in the country. However, this information is critical to comprehend the socio-economic contribution of bamboo to household livelihood and national economy that facilitate improved utilization and sustainable managements of these resources. It will explore the potential of the woodland ecosystem and bamboo products to supplement the national economy. The purpose of this study is to enhance the penetration of smallholder producers into lucrative markets through increased market information, value adding, processing, market access, forging of partnership and proportionally better share of consumer prices for bamboo products.

Materials and Methods

Assessment sites

Questionnaire survey has been conducted at Injibara and Bahir Dar in Amhara Regional State; Tikur Enchiny in Oromia Regional State; Chencha, Hagerselam, Masha and Hawassa in Southern Nations Nationalities and People Regional State; Pawe, Metekle, Asossa and Bambasi in Benshangul-Gumuz Regional State and Addis Ababa for bamboo with stakeholders involved in the sector.

Assessment approaches

Group discussion at regional, zonal and district levels: Intensive discussion has been made with mangers and experts of both government and NGOs on the basic issues regarding the sector and highly hot spot areas of bamboo growing pockets have been selected for household interview and observational assessments. The reasons for selecting the specific sites for the study assessment were: i. engagement of households in the sector is common practice in the sites; ii. close connection of these products to household livelihoods in the sites; iii.diversity and abundance of resources; and iv. existence of government and NGOs initiatives in the sector in those sites.

Collection of relevant documents and statistics: In the group discussion it had been briefed to the stakeholders the objective of the study and after they understand it well the desired data were provided to the assessment team. Data on resource situation and existing policy and strategy were collected from regional, zonal and district level bureaus and offices (totaling more than 30): Agriculture and Rural Development Bureaus, Trade and Industry Bureaus and NGOs offices. Statistical data for export and domestic markets were collected from Ethiopian Tourist Trade Enterprise (ETTE).

Survey and interview at village level: Since farmers are the implementers and direct beneficiaries of the bamboo sectors, households were selected randomly that the number of households were based on the homogeneity of the population, i.e. if the population of a particular pocket area is more or less homogeneous less number of households had been considered for interview. Accordingly 345 households for pocket selected bamboo growing areas were interviewed. The survey was directly focused on collecting information on the opportunities and challenges in the sector, annual cash income contribution from bamboo for households and the chains of marketing, harvesting and processing of such products.

Interviewing enterprises, cooperatives and firms: Nine bamboo based small firm owners, there bamboo yard owners, one bamboo based medium scale industry owner, one bamboo furniture making enterprise had been interviewed to provide information on marketing, processing, harvesting and the general opportunities and challenges excising in the country in general and at enterprise and/or firm level in particular.

Results and Discussion

Demography of bamboo harvesters

The survey has indicated that involvements in bamboo business are 43% and 27% of poor and middle households, respectively. The demography of respondents indicated that 28 % and 26% of the bamboo harvesters were above 50 and between 20 to 30 years of age respectively (table 1). From the same survey it has been recognized that 23% and 7% of the households responded as they use bamboo for food and charcoal, respectively.

Table 1: Involvement of households in bamboo business by age category

Age category	Frequency	Percent
<20	8	2.3
20-30	90	26.1
30-40	85	24.6
40-50	69	20.0
>50	93	27.0
Total	345	100.0

Bamboo in local economy

The socio-economic survey of 345 respondent households, of which about 53 % of them engaged on bamboo activity, table 9), has shown that the contribution of bamboo to rural economy is rated by 28.2% of households as very high, by 44% of them as high, 23% of them as medium and 5% of them as low. Its contribution to household cash income source is about 11% and correlation as a source of cash income with others options is also considerable significant (*0.03 < P< 0.001*). The profitability of bamboo business has been rated as high, medium and low by 31%, 42% and 26% of the respondent households respectively.

Table 2: Household category for cash income options in bamboo growing areas of Ethiopia

Cash income options	**Household category**					
	Engaged		Not engaged		Total	
	N	Percent	N	Percent	N	Percent
Crop production	304	88.1	41	11.9	345	100
Livestock	217	62.9	128	37.1	345	100
Wood products	50	14.5	295	85.5	345	100
Bamboo	184	53.3	161	46.7	345	100
Pity trade	89	25.8	256	74.2	345	100
Employment	15	4.3	330	95.7	345	100
Honey	69	20.0	276	80.0	345	100

Bamboo marketing integration

About 28%, 55% and 12% of respondents, respectively, replied as there is no linkage, poor linkage and moderate linkage in the vertical chain of bamboo marketing. While respondents that described the horizontal chain in bamboo marketing are sustainable - continuous, intermittent –unsustainable and variable on season are 16%, 55% and 29% respectively. Regarding the bamboo growers and traders relationship, 69% of the respondent households claimed that the relationship is exploitative type and 26% of them explained as the relationship is fair.

Nearly 88% of the respondents have replied that they sell their bamboo products including raw bamboo at local and road side market, 5% of them for regional market and 6% of them do not supply for the market but for self consumption. The respond of households for consumers' characteristics in the bamboo product marketing are as indicated in the table3. The market assessment at Hawasa has also indicated that the market price for different bamboo products was rewarding for those firm owners involved in bamboo based small scale industries (table 4). A similar assessment of bamboo yards in Addis Ababa indicated that the annual return from the sale of bamboo raw material depends on the owner's capital to brought sufficient resource from the sourcing sites (Table5).

Table 3. Consumers' characteristics in bamboo product use in Ethiopia

Consumers' characteristics	Respondents (N = 345)	
	Frequency	Percent
Bamboo product is considered as durable	63	18.4
Bamboo product is considered as not durable	27	7.8
Bamboo product is much less known	34	9.8
Bamboo product is preferred than timber	52	15.1
Bamboo product is not preferred than timber	87	25.3
Bamboo product is considered as "poor-man's" furniture	82	23.7

Table 4. Bamboo furniture price at Hawasa Market (August 2010)

Product	Sell price (Birr)	Cost of production, excluding labour	Net income, excluding labour
Bed 1.20 m	1300	585	715
Bed 1.50 m	1500	675	825
Table (80 cm X 50 cm)	250	113	137
Chair (40 cm X 40 cm)	200	90	110
Sofa – single seat	350	158	192
Sofa – double seats	600	270	330
Sofa – three seats	850	383	467
Sofa – complete sets	1500	675	825
Cupboard (1 m X 1.80 m)	850	383	467
Shelf – 4 parts	400	180	220
Shelf – 5 parts	450	203	247
Stool	80	36	44
Whisky bottle holder (partitioned)	1000	450	550
Dressing table	600	270	330

Table 5. Bamboo yard owners market analysis in Addis Ababa (August 2010)

Yard site	Average annual clum supply	Sourcing site	Average annual revenue	Average annual cost	Average annual net income
Merccato	20,000	Guraghe	170,000.00	99,680.00	70,320.00
Ras Desta	1,000	Injibara	15,850.00	12,050.00	3,800.00
Total	**21,000**		**185,850**	**111,730**	**74,120**

Bamboo value chain analysis

From the survey of different firms and enterprises in Ethiopia it has recognized that the quality of bamboo products for the export market is not as to the desired specification and standard. Most of the bamboo products are traditional and used for local markets except some initiative to produce charcoal, curtains, briquette and sandal stick by some medium scale enterprise such as Adal Industrial Engineering Plc. Whereas production of good quality product for the market will minimize the increasingly stern competition, enables producers, processors and retailers track their products through the value chain, and deserve premiums for a consistently high quality produced and processed product. In addition if producers, processors and marketers are working together, there will be opportunities to lower costs and increase efficiencies in the market. On the other hand, consumers demanded differentiated products that have high and consistence quality and cannot be duplicated. They can provide unique and superior value to the buyer in terms of product quality, special features or after sales service.

The white arrows in the marketing loops for bamboo in Ethiopia (Figure 2) are just to indicate that the marketing integrations and the value chain at the level of processing and then marketing of processed products are very weak.

- *Process upgrading* - an introduction of improved machinery for bamboo splitting and cutting, such as by Adal Industrial Engineering Plc, were some of the initiatives of process upgrading observed during field survey;
- *Product upgrading* - examples of product upgrading observed during field survey includes diversifying from traditional bamboo products such as grain store, baskets, chairs and tables, into modern ones such as curtains, sandal sticks, briquettes, match sticks, etc which have very high value in niche markets;
- *Functional upgrading* - there are bamboo based enterprise such as Ethiopian Tourist Trade Enterprise and Adal Industrial Engineering Plc. for example,

that take on new functions such as export marketing, or taking on new and more lucrative roles within the value chain; and

- *Chain upgrading* - there are some initiatives to produce new products such as lumber and curtains, which are not initiated previously, for marketing by establishing a new value chain.

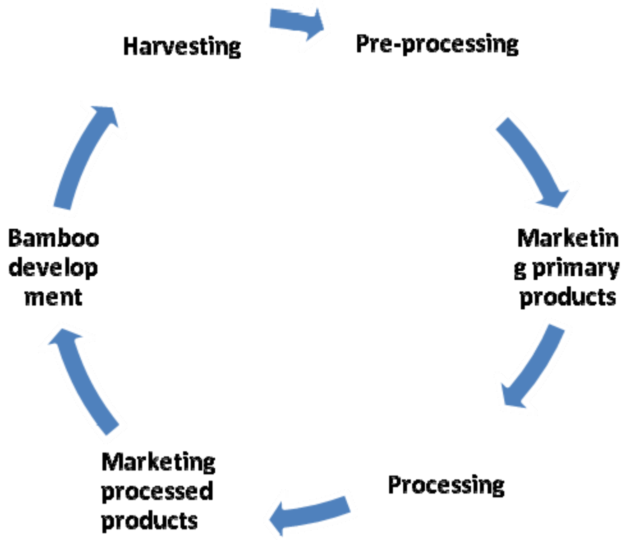

Figure 1. The marketing loop of bamboo in Ethiopia

Bamboo Production-to-Consumption System

From the value chain analysis it has been identified that there were three dimensions in the production – to – consumption system of bamboo. The first is vertical dimension, the flow of raw bamboo from its production in a natural or cultivated system, through the various transactions and processes, to the final consumer. Second, horizontal dimension, concerns the set of bamboo based firms operating at a particular point in the market chain and the scale of activity and relationships among them. And third is that of intensity which relates to the amount of labour and capital that is used to carry out a particular function. The price and intensity both increase at each stage of the hierarchical vertical dimension as well as at each firm level at the horizontal dimension.

The value chain in Ethiopia is hardly concerned to export market. Almost all products produced from bamboo are produced traditionally and manually and used for domestic market except some infant efforts to export few products. When the quality of the product produced is of improved level and the value added is high it helps the producers, processors and marketers to maximize their profit (Table 6). The ETTE is one of the government institutions that produce bamboo furniture with its own specification and sell its products to national as well as international tourists domestically but not at export level (Table 7).

Table 7. Value addition in Addis Ababa for maximizing profit from product sells (October 2010)

Product type	*Firm 1 value added is high*			*Firm 2 Value added is low*		
	Production cost	*Selling price*	***Profit (birr)***	*Production cost*	*Selling price*	***Profit***
Chair	250.00	350.00	**100.00**	30.00	40.00	**10.00**
Table	120.00	200.00	**80.00**	20.00	50.00	**30.00**
Shelf	130.00	200.00	**70.00**	70.00	95.00	**25.00**
Bed	600.00	1,200.00	**600.00**	100.00	130.00	**30.00**
Partition	250.00	350.00	**100.00**	-	-	-
Sofa	-	-	-	40.00	60.00	**20.00**
Stool	-	-	-	15.00	20.00	**5.00**
Mat	-	-	-	15.00	20.00	**5.00**

Table 8. Bamboo furniture making and selling price by ETTE (October 2010)

Furniture type	**SPECIFICATION**				Selling price (Birr)
	A(cm^2)	FH (cm)	BH (cm)	Colour	
Chair	43 X 43	46	100	Varnished/natural/brown	159.50
Chair with design	47 X 46	46	86	Varnished/natural/ brown	210.00
Chair with design	45 X 42	46	94	Varnished/Natural/brown/green	159.50
Sofa(single seater)	55 X 60	42	76	Natural/brown	110.00
Sofa(double seater)	110 X 69	42	76	Natural/brown	219.00
Garden chair	54 X 70	33	67	Natural/brown	330.00
Coffee table	80 X 50	50	50	Varnished/natural/brown	227.00
Dining table	80 X 80	77	77	Varnished/natural/brown	465.00
Partition	174 X 5	170	170	Varnished/natural/brown	576.00
Partition with leather	150 X 5	185	185	Varnished/natural/brown	987.00
Bed	135 X 205	45	100	Varnished/natural/brown	1391.00
Bedside drawer	45 X 40	58	78	Varnished/natural/brown	312.00
Drawer(5 parts)	80 X 50	90	90	Varnished/natural/brown	695.00
Shelf	75 X 42	170	170	Natural/brown	427.00
Shelf	90 X 42	105	105	Natural/brown	246.00

A= seater area; FH= front height; BH = back height.

Challenges in the bamboo sector

- Shortage of raw bamboo as required- supply is not with the required size and there is also transport problem and confiscation at check points;
- Lack of technical skills for machine operation and lack of technical tools;
- People's view to bamboo products is low;

- Immature raw bamboo has been mixed with the matured ones and sold to the processors by the farmers- the immature bamboo is not suitable for making furniture;
- Bamboo have substituted by eucalypts in some areas as the market value of eucalypts is found to be higher than bamboo at the current market condition;
- There is loss of resource during the processing of raw bamboo into different products;
- Difficulty of transporting bamboo from resource base to Addis, the supply chain is not sustainable irrespective of increase in demand in bamboo products by the consumers which the firm owners cannot meet it easily; intermediaries play their own role in the market chain;
- General government policy is good, but there is no separate policy for bamboo sector;
- Bamboo control at check points had created shortage of supply;
- There is difficulty of differentiation between products of bamboo and *Arondo donex;*
- Incorporation of damaged and immature bamboo culms in to the lorry load by suppliers;
- There is international demand for lumber and curtains, but difficult to compete China markets;
- Lack of credit due to collateral problem plus high interest rate;
- Insufficient training on technical expertise on how to make bamboo products, the one the firm owners make are traditional;
- Lack of production and display site to promote bamboo products;
- Lack of machinery to process and produce quality bamboo products which fulfill customers' demand;
- There is insect problem which damages bamboo products and this will reduce the price;
- Unable to compete with more capable bamboo firm owners for the same product and for the same market;
- Different interest of individual firm owners not to organize in to cooperative which can enable them to set common market price and build their capacity to compete in the business;
- Bamboo resource base is decreased as compared to 5 years ago due to the reason that harvesting is much greater than its development and bamboo product demand is increased;
- The regulation in bamboo harvesting is loose as the middle men bought the raw bamboo from farmers and supply to urban based bamboo firm owners which they only see their profit without due care for the conservation of the resource;
- The use of bamboo products is much less known and considered as "poor-man's" furniture by consumers;

- The horizontal chain(supply chain) is intermittent and unsustainable to urban bamboo based SSF and the vertical chain is moderately linked to each other and the value adding system is low-tech processing;
- Even if bamboo based business provide rewarding profit there is little process and product upgrading by those who involve in the business and there is lack of functional and chain upgrading;
- Consumers prefer wood products than bamboo ones – low market demand – products will stay long in the store and will be damaged by insects;
- Bamboo products are made by manual and traditional methods; takes long time to complete a single product;
- Narrow workshop by individual firm owners is a drawback to undertake proper operation and produce the desired quality products; and
- New bamboo products cannot be purchased by consumers easily because most of the consumers do not know bamboo products, it then need great promotional work.

Opportunities in the bamboo sector

- Availability of potential resource base;
- Availability of indigenous knowledge;
- Potential market either nationally or internationally;
- Interest of potential investors to involve in the sector;
- Easy regenerative ability and fast growth rate of bamboo;
- Encouraging policy in the country as well as in the regions where bamboo is growing;
- Bamboo is environmentally friendly;
- Easy for the process of product diversity;
- Increased involvement of individuals in small scale bamboo based enterprises;
- Emerging NGOs to provide funding and training support for those involved in the bamboo business;
- Increased attention from the government and other supportive bodies for the sector;
- Media coverage has been given by international media agencies including BBC;
- Government exempts tax for machinery purchase and provide bank loan for those involved in the activity; and
- There are good beginning by some bamboo based industry to produce value added products such as tooth sticks, lumber, charcoal, sandal sticks, briquettes and curtains which are different from the traditional products;

Conclusion and Recommendations

- The present bamboo processing is still traditional. There is a need in technological promotion;
- The potential of bamboo resources in Ethiopia in general and in bamboo growing regions in particular is not utilized to the required level. Strategy should be developed to use this potential properly;
- Farmers should be supported with modern technology in bamboo propagation methods;
- There is a need in product diversification based on consumer needs;
- Focus on conservation and training of farmers;
- Focus on bamboo insect pests and disease management and protection;
- Establishment of technical training center at each bamboo growing regional states;
- Encouraging those individual investors who have an interest in the sector; and
- Establishing collaborative networks with national and international organizations that work in the sector.

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Physicochemical Characteristics of Bamboo Shoots from *Yushania alpina* and *Oxytenanthera abyssinica* growing in Ethiopia

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Introduction

Bamboo belongs to the family of Gramineae which has over 1200 species in 50 genera of bambuosidaea which mainly grow in the tropics and subtropics (Anonymous, 2002). It is a source of food, fodder, furniture, building materials, energy and medicine. Though, the bamboo shoots have been used as food for over 2500 years in Asia, analysis of its nutritional quality is more advanced in Asia than elsewhere.

Ethiopia has two bamboo species namely the African alpine bamboo *Y. alpina* (K. Schumann) Lin which grows at an altitude between 2200-4000 m and the lowland bamboo *O. abyssinica* (A. Richard) Munro which grows at 1200- 1800 m a.s.l (Embaye et al, 2003; Embaye et al, 2005). In Ethiopia the use of bamboo is very limited dominantly for fencing, house construction (tukul), waving and household furniture, household energy; and in some areas of the country the shoots are also used for food. The area coverage of this huge resource of the country is estimated over 525 thousands ha (Anonymous, 2004). There is a growing attention in the characterization of biological characteristics and products of these versatile and valuable resources (Embaye et al, 2003; Embaye *et al*. 2005; Seyoum *et al,* 2007).

Bamboo shoots usually emerge at the early stage of the rainy season, the shoot production season is from May to June but it depends on location and species, after the first rainy shower. The quality of the shoots for food depends on the biological characteristics of the bamboo species.

Reports indicatd that bamboo shoots may contain hydrogen cyanide as much amounts as reported for cassava tubers, however, the cyanide content is reported to decrease substantially following harvesting and subsequently by adequate processing to break down the cyanogenic glycoside (Agatemor, 2009). The local communities in Masha and Assosa, southwest of Ethiopia, areas use bamboo shoots as a food during shortage of food crops. During bamboo shoots preparation the local people in the areas of south west and western parts of Ethiopia, they boil it two-three times and drain the water. This traditional preparation technique may reflect the need for removal of either the bitterness or the natural toxicants prior to consumption.

The objective of this study was to evaluate some of the nutritive properties of widely growing bamboo species of the *Yushina alpina* (synonymous*Arundinaria alpina)* and *Oxytenanthera abyssinica* bamboo shoots used for food in south west and western parts of Ethiopia.

Materials and Methods

Lowland bamboo shoots *(Oxytenanthera abyssinica)* were collected from Asossa, Pawi and Didessa while those of the highland bamboo shoots (*Y.a alpina*) were collected from Injibara, Masha and Tikure Inchini. The shoots were immediately picked as they were come out from the ground with in the first two to three days. Both types of samples were transported to the laboratory in liquid nitrogen.

For the analysis of bamboo shoots we followed the preparation method of the local community procedures. The hard sheath, the bottom and top portions of the shoots were removed mechanically and the remaining middle portions of the shoots which account for over 45% of the emerging ones were washed three times in cold water.

For further work the middle portion of bamboo shoots were sliced at the thickness of 5 mm, oven dried at a temperature of 105 ^{0}C for 3 hours and then at 40 ^{0}C for the next 4 ??? hour using forced hot air oven drier. The moisture content for both species was above 90%.

Fat extraction
The bamboo shoots were extracted with hexane in a Soxtec apparatus a product of Germany and the average reading of six replicates of each sample analysis were done.

Ash determination
A sample of the bamboo shoots was first heated on a burner and then burned in a furnace at 550 °C. The Ash content was expressed as a percentage ratio of the weight of the ash to the oven dry weight.

Nitrogen Content

Nitrogen analysis was undertaken using Khedjal Distillation Apparatus. The amount of nitrogen was calculated by the amount of acid added that change the colour of the distilled bamboo shoot solution. The protein content was calculated using the nitrogen conversion factor (NCF) 6.25 (Greenfield and Southgate, 2003).

Mineral Content

The mineral content determination of the studied samples, except for phosphorous, were done by Atomic Absorption Spectrometer. Wet ash method was used for the determination of phosphorous content in the bamboo shoot samples using UV-VIS spectrometer at 400 nm as indicated by Yebeyen et al. (2009).

Statistical analysis

Results are expressed as the means of three separate replicate measurments, except for fat which were replicated six time in three sites. One-way analysis of variance [ANOVA] were analyzed by statistical software SAS. Means were compared by least significant difference at 5% level.

Results and Discussion

The fat (oil) extracted from both species has a light yellow colour. The fat content of *Y. alpina* bamboo shoots was on average 1.09%. The analysis showed that the shots from Masha site was lower in fat content which makes it to differ significantly from the other two locations (Figure 1a). The highland bamboo shoot*alpine* has a lower crude fat content in comparison with the Chinese highland bamboo, *Fargesia yunnanensised,* as reported by *Wang* et al. (2009). The lowland bamboo shoots collected from Assosa, Dedessa and Pawe areas on average the fat extract was 1.44%. The shoots collected from Pawe area were significantly different in its fat content from the other two locations (Figure 1b).

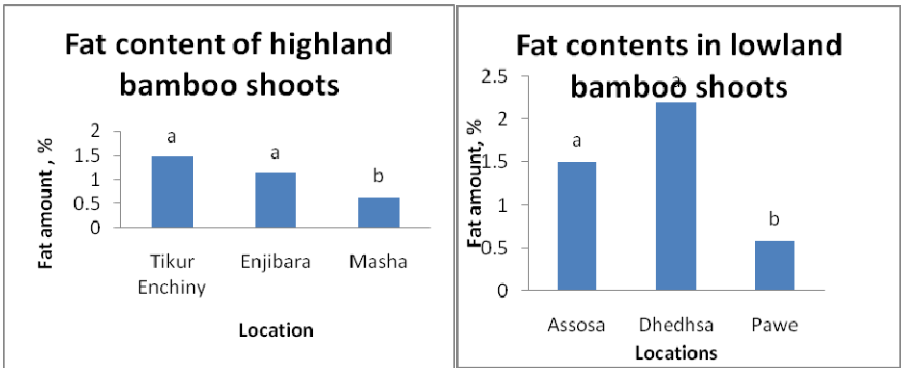

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Figure 1. Fat amount of bamboo shoot species.
Means with similar letters for comparison between different sites are not significantly different at p= 0.05.

The ash content of highland bamboo shoots *alpine* collected from the three sites range from 14.2-17.1%. The analysis of the ash content of the highland bamboo shoots significantly varies from location to location. The lowest ash amount in the shoot was 14% and the highest was 18% for samples of Tikure Incheni and Masha, respectively. The ash amount from Dedessa site bamboo shoot shows a significant difference from that of Assosa samples. Similarly, high amount of ash contents from bamboo shoots of *Fargesia yunnanensis* was also reported by Wang et al. (2009) but very far from INBAR data reports (Anonymous, 2002).

The nitrogen content of the bamboo shoots of *Y..alpina* from Tikure Incheni, Injebara and Masha areas were in the range of 4.15 – 6.22 %. The nitrogen content of the Tikure Incheni site shoots significantly different from other locations (Figure 2a). The average nitrogen content for lowland bamboo shoots was 3.29%, 3.99% and 2.95% for samples of Assosa, Dedessa and Pawe, respectively. There was no significant difference in nitrogen content of the lowland bamboo shoots in locations (Figure 2b). The protein amount of the shoots can be calculated by multiplying the average nitrogen content of each site by 6.25 which is a common factor for food crops as indicated by Greenfield and Southgate (2003) and Anonymous (1998).

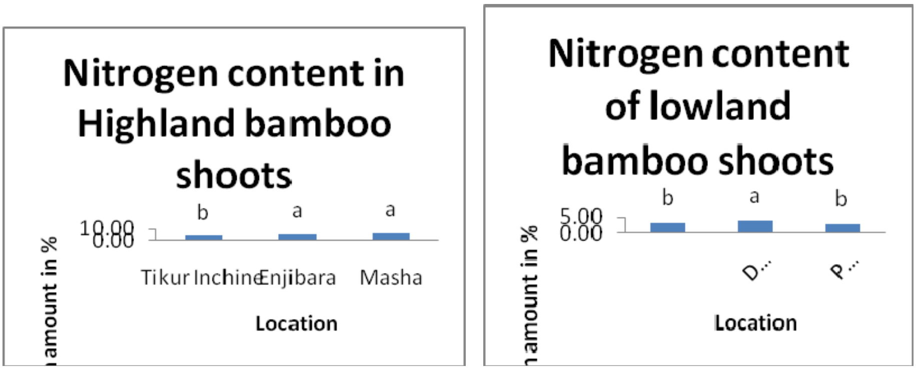

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Figure 2. Nitrogen amount in bamboo shoots of indeginous species.
Means with similar letters for comparison between different sites are not significantly different at p= 0.05.

The calcium content of the bamboo shoots of *Y.. alpina* was analyzed and found that of the Tikure Incheni site was lower and significantly different from other sites (Figure 3a). The low calcium content observed for the bamboo shoots of Tikure Incheni was well related to the low ash content of the sampled material from the specified location. The calcium content of the shoots of *O. abyssinica* collected from Assosa, Dedessa and Pawe were 0.09 %, 0.12% and 0.15%, respectively. There was a significant difference in calcium content of the shoots from Assosa, Dedessa and Pawe areas (Figure 3b).

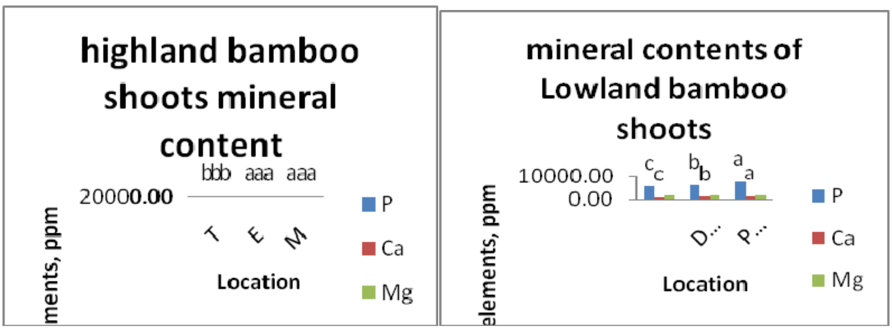

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Figure 3. Mineral elements in bamboo shoots of indigenous species
Means with similar letters for comparison between different sites are not significantly different at p= 0.05.

The analysis for magnesium content in the bamboo shoots of *Y.. alpina* collected from Tikure Incheni, Injebara and Masha was in the range of 1386 - 1850 ppm. The analysis showed that the Tikure Incheni site bamboo shoot significantly differs from other locations in its magnesium content (Figure 3a). On the other hand, the shoots of *O. abyssinica* collected from Assosa, Dedessa and Pawe found to be in the range of 1903.33-1986.67 ppm, respectively. From the analysis it was observed that the magnesium content in the shoots of *O. abyssinca* was similar and there was no significant difference between the shoots of different locations (Figure 3b).

The potassium content in the bamboo shoots of *Y.. alpina* was 8.54%, 9.08% and 9.77% for Tikure Incheni, Injebara and Masha, respectively. The potassium content showed that all the three sites were significantly different from each other. The potassium content in *O. abyssinica* bamboo shoots collected from Assosa, Dedessa and Pawe were found to be 6.63%, 7.03% and 7.15%, respectively. The statistical analysis revealed that the potassium amount in bamboo shoots from Assosa site was significantly different from other locations.

The iron content in the bamboo shoots of *Y.. alpina* was 0.004%, 0.01% and 0.02% for Tikure Incheni, Injebara and Masha, respectively. The iron content in the bamboo shoots of all the three sites was significantly different between locations (Table 1). The average iron contents in *O. abyssinica* bamboo shoots collected from Assosa, Dedessa and Pawe were 0.003%, 0.01% and 0.01%, respectively. The analysis for iron content for lowland bamboo shoots was significantly different from site to site.

Conclusion

The analysis of bamboo shoots of *Y.. alpina* collected from three locations showed that the bamboo shoots collected from Tikure Incheni area was lowest in all analysed minerals content namely phosphorous, calcium, potassium, magnesium, iron and nitrogen content hence low in protein contents too. The lowland bamboo shoots of *O. abyssinica* except for the magnesium, all samples differ in their mineral elements content and the bamboo shoots from Assosa area showed the lowest values.

The macronutrient mineral elements N, P and K, the secondary nutrient Ca and Mg, and from the micronutrients Mn, Cu, Zn and Fe amount in the bamboo shoots of *Y. alpina* were determined and high amount of Fe was recorded for Masha site samples. Sample analysis of both bamboo species of Ethiopia indicated that the order of nutrient elements have variations and for *O. abyssinica* bamboo shoots the order decreasing is K > N > P > Ca > Mg, for the *Y. alpina* the order decreasing of these K > N > P > Mg > Ca, in both species the potassium amount is high.

Dissemination of the bamboo shoots consumption practice to other bamboo growing areas of the country will contribute to the food habit diversification, balanced diet due to the high amount of protein content and food self-sufficiency. The harvest of bamboo should follow the bamboo shoot management harmonised with the traditional knowledge of the community on bamboo shoots.

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Edible Oil Extraction from *Podocarpus falcatus*

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Introduction

Podocarpus falcatus (Thunb.), which belongs to the family Podocarpaceae, is an evergreen tree up to 46 m in nature with a long clean and cylindrical trunk. The species is native to East and Southern Africa from Sudan to the north, Congo to the west and Cape Province to the south. It is found in various types of vegetation, including Afromontane forest. In Afromontane forest it is frequently one of the dominant or co-dominant species (*Podocarpus* forest or *Juniperus*-*Podocarpus* forest). It is often seen persisting in patches of relic forest and as a single tree, left in derived grassland or farmland. It grows at 1500-3000 m altitude in areas with 1200-1800 mm rainfall/ year (Brithenbach, 1963; Bekele-Tesemma et al., 1993; Legesse, 1995). In Ethiopia *P. falcatus* was profoundly found in Arsi, Bale, East of lake Awasa, Jemjem and the Megada forests of Sidamo and Wollega (Legesse, 1995; Getachew et al., 2005). Due to the intensive utilization of the species for its timber, it is currently found in the highlands as a scattered tree in farmlands and patches around riverbanks.

P. falcatus is a suitable source of timber and firewood. The timber of *Podocarpus* is used for construction, bakery boards, cupboards, shelves, bed and so on. The lightwood of high quality is widely used for furniture, panelling, shelving, drawer linings, shop counters and light duty impregnated railway sleepers (WUARC, 1995). Being free of odor and taste, it is the wood most used locally for butter and cheese boxes and other food containers. Its timber is of high quality with very fine grain, the density varying from 480 to 599 kg/m^3 at 12-15% moisture content (WUARC, 1995; Dorthe, 2003).

P. falcatus provides various non-timber uses and services like soil and water conservation, as shade tree for coffee, aesthetic value, feed and shelter for animals. The ripe fruit is edible by animals but very resinous. For instance, the Columbus monkey is highly dependent on *Podocarpus* for shelter and the fruits for feed. The seeds of the species also bear oil which is edible by human beings and has medical value. It is used as medicine against gonorrhea (Brithenbach, 1963; Demel, 1994; Legese, 1995). There is typically heavy seeding at intervals of 2-4 years (Chalk et al., 1935). The sap is used as a remedy for chest complaints. The large, dense crown makes it suitable for shade and windbreaks and the attractive shape has made it popular as an ornamental tree in cities. In some countries, it is used as a Christmas tree instead of pine or fir. In the natural environment, the species is an important provider of nesting sites and food for a number of bird species. *Podocarpus* is one of the indigenous tree species of Ethiopia that has been intensively harvested for its good quality timber. Overexploitation for the timber together with its slow growing nature is leading the species to drastic reduction in population and distribution.

To conserve the population and increase the distribution of this species needs attention in the exploration and exercise of its non-timber value. Searching of values for some agricultural by-products and industrial waste products has been recently focused (Tarek, 2001). Such utilization would contribute to maximizing available resources and results in the production of new products. Hence, identification and promotion of the non-timber uses of such endangered indigenous and slow growing tree species is imperative for the conservation of the remnant trees. Therefore, the general objective of the study was to investigate and promote the non-timber values (edible oil) of *P. falcatus* in order to increase the contribution of the species to food security while ensuring conservation of the remnant *Podocarpus* population.

Materials and Methods

Sample collection and preparation

Fruits of *P. falcatus* were collected from five sites, namely Ticho, Assela, Kersa, Hirna and Degaga sites. From each site five mature trees were randomly selected and five kilograms (dry weight) of fruit were collected and oil from the samples collected in each tree were separately extracted and measured.

Oil extraction

Five key informants were systematically selected in Ticho area that have an experience on and engaged in traditional extraction of *Podocarpus* fruit oil to collect and document the traditional oil extraction methods in the area. The key informants were interviewed and direct observations and measurements were made while they are extracting oil from the *Podocarpus* fruits. The oil yield per a given amount of seed kernel of the species following the traditional extraction method was done by giving each of the key informants a kilogram of kernel and measuring the oil yield. Information on the local uses of the oil was also collected.

Oil Extraction and chemical analysis

The collected fruits were spread under shade for drying with frequent monitoring for fungal growth and decay. The hard seed coat was manually removed from the collected seeds; the oil was extracted using traditional methods and solvent (Soxhlet) extraction methods using hexane as a solvent. The physico-chemical properties such as oil content, refractive index, saponification value, specific gravity, acid value, iodine value and peroxide value and contaminants level such as moisture and volatile matter, insoluble impurities and soap content of the oil sample from the species were analyzed according to ISO respective methods at the Ethiopian Quality and Standard Authority.

Data analysis

Results are expressed as the mean values of the duplicate determinations. The data on mean oil content of the seed kernels from the five sites were statistically analysed using analysis of variance (ANOVA). Significant differences between any two means were determined at the p= 0.05 level.

Results and Discussion

Oil content

The average oil content of *P. falcatus* kernel samples using Soxhlet extraction was found to be 51.37% by weight of dry kernel, the maximum being 55.47% from samples in Hirna site and the minimum 49.58% from Kersa site. The seed samples collected from Ticho, Assela, and Degaga yields oil content of 53.51%, 52.11% and 53.37%, respectively. The seed oil content of the species appears very promising for edible purpose and other purposes like soap production. The oil content is much higher than that of the common oil crops like niger seed (40% by weight of dry kernel) and oil yielding tree species such as *Moringa stenopetala* (32.5% by weight of dry kernel) and *Terminalia bellirica* (47% by weight of dry kernel) (Annonymous, 1990; Nag et al., 1995; Shiferaw et al., 2004). This finding may focus an interest on *P. falcatus* seed kernels as high oil sources.

On the other hand, analysis of variance suggested that there were no significant variation (P= 0.8857) in oil content among the sites where the seed samples were collected. This could be attributed to the closeness in location and similarity in the climatic conditions of the study sites.

There are about 300 dry seeds/kilogram (Borota, 1975). On the other hand, Munyarugerero (1983 as cited in Kabera, 1990) reported that 80 to 100 seeds per kilogram without the seed coat (exocarp) and 140-160 seeds/ kilogram with the seed coat. Variation in seed weight may reflect the environment where seeds develop: the harsher the environment, the smaller the seeds. Though, there are no research-based reports on the amount of the seeds produced by individual trees, according to Kabera (1990) a mature tree can yield 0.25 tones of fresh seeds in one season. Based on the measurements taken during the present study, an average of 250 gm (25%) kernel was found from a kilogram of dry seed and on average 0.5 liter of oil was extracted from a kilogram of kernel by the traditional extraction method. Accordingly, about 31.5 liter of oil can be extracted form seeds of a single mature tree. Therefore, promotion of the extraction of such non-timber product from the species and value adding processes will have significant role towards the conservation and sustainablity of the ecological and socio-economic benefits from the remnant trees of *P. falcatus* in the highlands of Ethiopia.

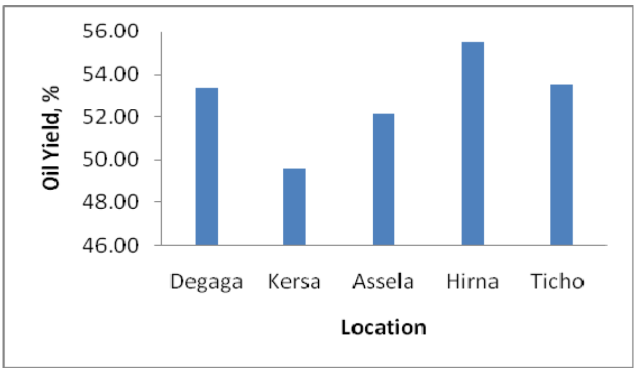

Figure 1. Mean oil Yield of Podocarpus seed kernel from different locations

The traditional/indigenous extraction method

The traditional extraction method is compiled based on the data gathered from the key informants and the observation and measurements taken during oil extraction by the local people in Ticho area. The steps followed are summarized below:

- Collection of mature fruits fallen beneath the trees and spreading for further drying;
- Depulping/separating the pulp/flesh from the seeds: This is done by socking the fruits in water and crushing using wooden mortar. Then, spread for drying and blow by wind to separate the pulp /flesh;
- Separating the kernel: the seeds will be grinded to separate the kernel/inner part then blow to screen the kernel from the seed coat;
- Roasting the kernels using metal sheets: This step will take 5-7 minutes depending on the desired final color of the oil that is 5 minutes for green and 7 minutes for brown color oil;
- Crushing the roasted kernels using stone mill;
- Mixing the crushed kernels using hot water for about 8 minutes: the crushed kernels will be thoroughly mixed by hand until it starts to produce some oil floating;
- Boiling the mixture by thoroughly mixing for about 35 minutes: the mixture will be poured into a pot with boiling water and heated for about 35 minutes by thoroughly steering;
- Filtering the oil: the pot will be taken out of the fire and stayed for a while to allow the oil floating and the crude settling down. Then, the oil will be poured into a bottle or any other container. At this stage some spices will be added to give a pleasant smell and test to the oil; and
- Repeating the steps 7 and 8 up to three times to extract the oil exhaustively.

Based on the present study an average of 250 gm of kernel was found from a kilogram of dry seed. Following the traditional extraction method an average of half litter (500 ml) oil was extracted from a kilogram of kernel. The result is a bit lower than the average oil content obtained by Soxhlet extraction that is 51.37% by weight of dry kernel. Locally the extracted oil is used for edible purpose, specially for cooking chicken in holydays. The byproduct of the extraction that is the hard seed coat obtained while extracting the kernel is believed by the local people to have a high calorific value and used as source of energy. The traditional extraction follow heat extraction method, which is simple, and can easily applied using local materials so that other interested farmers can adopt it with little effort.

Physicochemical properties of Podocarpus oil

The analysis of chemical and physical properties of the oil sample such as acid value, iodine value and peroxide value and contaminants level such as moisture and volatile matter, insoluble impurities and soap content of the oil sample from the species are in progress in the Ethiopian quality and Standard Authority. However, some of the determined physical properties of the oil of

P.falcatus seed kernel such as refractive index (25^0C), specific gravity (25^0C) and saponification value are shown in Table 1.

The specific gravity of the oil extracted from the kernels of *P .falcatus* (0.896 ± 0.021) compared well with the specification given for edible oils from common oil seeds (0.910-0.927) by the Ethiopian Standards and watermelon seed kernel oil (0.919) as reported by Tarek (2001). However, the saponification value (190.34 ± 33.81) was higher than that of the specification of the oils from common oil seeds and watermelon. On the other hand, the refractive index of *P. falcatus* kernel oil (1.472 ± 0.006) was also comparable with the specification given for edible oils from common oil seeds (Annonymous, 1990).

Significant difference ($p= 0.001$) was observed among the sites where the seed samples were collected in the specific gravity and saponification value of the oil extracted. However, no significant variation was found between the provenances in refractive index of their oil.

Conclusion and Recommendations

Podocarpus seed kernel owing to its high oil content and comparable properties with other oil crops, it could be used in the production of human diet and in the manufacture of soaps. The production of oil from the podo seed kernel will contribute to the conservation and efficient utilization of the podo trees by planting the species and managing in the home garden and other degraded areas where it environmentally suit. Therefore, we recommend popularizing and scaling- up the indigenous knowledge on the use and production of edible oil from the podo species by which it scale up the planting of the species for income generation.

Table 1. comparison of some properties of *P. falcatus* kernel oil with specification of properties of oil from common oil seed

Property	*P. falcatus* kernel oil	Specifications of oils from common oil seeds					
		Niger seed oil [a]	Cotton **oil** [a]	Linseed oil [a]	Rape seed oil [a]	Sun flower oil [a]	Watermelon kernel oil [b]
Refractive index (25 ^{0}c)	1.472 ± 0.006	1.466-1.47	1.458-1.460	1.472-1.482	1.465-1.469	1.467-1.469	1.469
Specific gravity (25 ^{0}c)	0.896 ± 0.021	0.925-0.927	0.918-0.926	0.912-0.9133	0.910-0.920	0.918-0.923	0.919
Saponification value	190.34 ± 33.81	188-192	189-198	188-195	168-181	188-194	201

Source: [a] Ethiopian Quality and Standards Authority (2001), [b]Tarek et al (2001)

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Suitable Eucalyptus Species for Particleboard Manufacture

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Introduction

It's well known that *Eucalyptus* is one of the most widely distributed plantation timber trees in Ethiopia. This species is an ideal tree for wood-based boards manufacture factories. Currently all logs available to particleboard factories are comes from *Eucalyptu* plantations.

Almost all board processing factories are using only *Eucalyptus globules* to produce their products. However, due to lack of knowledge other *Eucalyptus* tree species are not used as a raw material for wood-based factories. Identifying other eucalyptus species which are more suitable for boards manufacturing is essential. Species selection is one of the most significant factors for boards manufacture and it governs the type of products that can be generated economically (Vital *et al*, 1974). Especially there is lack of information in this country how wood density or age variation is affecting technological properties processing methods and costs of the products. As stated by Maloney (1993) the most important species variable governing board property is the density of the raw material.

Wood density has significant influence not only on products properties but also on processing. Particleboards made from lower-density species have a greater bending strength, internal bond, modulus of elasticity, screw withdrawal, water absorption and thickness swelling. The reason for this lies in the fact that a given weight of particles from a lightweight wood species occupies a greater volume than the same weight of similar particle from a dense wood (Moslemi, 1974). Wood density has significant influence on the consumption of resin content, pressing time and press temperature. All these factors have also very high significant effects on costs and quality of particleboards. To gather adequate information on lesser-known Eucalyptus species can offer opportunity to expand industrial plantations on vast areas. Based on these concepts the objectives of this study were to select suitable eucalyptus species and identify appropriate harvesting ages used for particleboard manufacture.

Three eucalyptus species namely *Eucalyptus camaldulensis, Eucalyptus globules* and *Eucalyptus saligna* were selected for this study. Trees stands representing 9, 14 and 19 year age classes, were identified for each species. Three cubic meter of timber for each age classes and a total of 27 cubic meters of eucalyptus timber were harvested from Gimbi and Entoto in 2010. Trees were selected primarily due to their very similar characteristics except their age variation. Then all harvested logs were transported to Ethiopian Chip Wood Factory (ECAFCO) for board manufacturing.

Material and Methods

Board manufacturing

All sample logs were debarked manually prior to chopping by drum chipper. Then sample logs were chipped to the required dimension of particles. The particles were then screened on a circular vibrating screener and accepted particles were dried to 8% MC in an air blow drier. The dried particles were blended with resin, a solution of hardener and wax in glue mixing line. 10 % resin contents of urea formaldehyde resin (based on the oven-dry weight of the particle) was used as a binder. 3 % solution of ammonium chloride (based the solid content resin) and 1% of liquid wax emulsion (based on the oven-dry weight of the particle) used as hardener and to impart water repellency. Then the semi-moist furnish were passed through forming station and pressed for about 6 minutes in hot press and a total of 27 three-layer boards were manufactured.

Properties used for board evaluation

The mechanical properties, board density and dimensional stability of three-layer eucalyptus particleboards were evaluated according to the International Standards Organization (ISO) (Anonymous, 2003a) for wood-based panel products. The Modulus of Elasticity (MOE) and Modulus of Rapture (MOR) were determined in accordance with ISO/DIS 16978 (Anonymous, 2003b) by applying a load to the centre of a test piece supported at two points over a span of 320 mm.

The increment in thickness swelling (TS) and water absorption (WA) of specimens after 24 hours of soaking in water was determined in accordance with ISO/DIS 16983 as percentage of the original thickness and weight (Anonymous, 2003c).

Experimental design and analyses

Completely randomized design (CRD) with factorial experiment was used to conduct this experiment. Microsoft excel 2007 was used to evaluate the mean comparisons.

Result and Discussion

The mean densities of eucalyptus particleboards obtained from 3 age groups were significantly different among species and age groups (Figure 1).

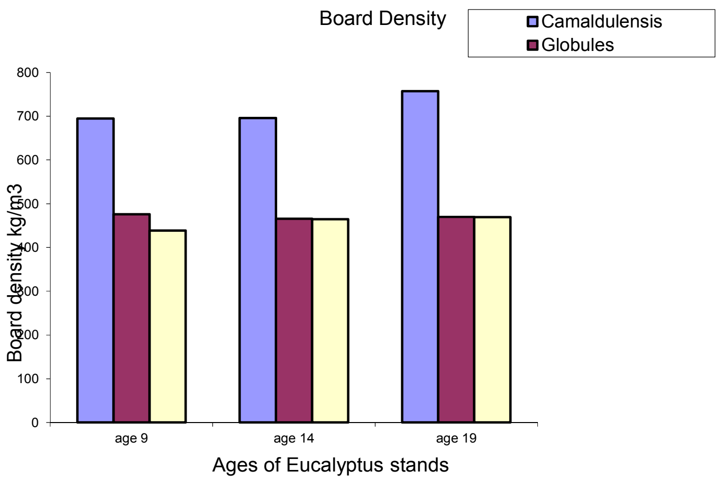

Figure 1. Effects of species and age on board density

As indicated in Figure 1 nine year-old *E. saligna* had low board density (438.45 kg/m^3) than *E. globules* (476.03 kg/m^3) and *E. camaldulensis* (694.35 kg/m^3). On the other hand, when comparing three eucalyptus species, *E. camaldulensis* had significantly high board density than *E. globules* and *E. saligna* in all age-groups. The results of this experiment showed that with increases of eucalyptus stand growth age the density of boards were increasing. Based on this results it's possible to recommend that harvesting eucalyptus species at nine year-old can give better quality boards than stands those harvested at 14 and 19 years-old. Comparing board density between species *E. saligna* and *E. globules* manufactured from 9 years-old are more suitable for board manufacturing than *E. camaldulensis*. As stated by Maloney (1993) the most important species variable governing board property is the density of the raw material.

Species with low board densities are preferable for particleboards manufacturing, because they need low resin consumption, low temperature, low pressure and short press closing speed (Suchsland, 1967; Kelly, 1977; Nishimura *et al*., 2001)

Strength Properties (MOR and MOE)

Figures 2a and 2b show the effects of eucalyptus species and age variations on MOR and MOE of three-layer particleboards.

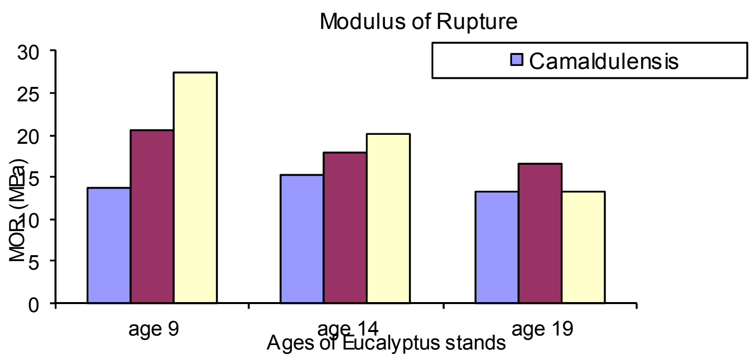

Figure 2a. Effects of species and age on MOR.

As shown in figure 2a boards obtained from 9 year-old *E. saligna* had the highest MOR (27.48 MPa) than *E. globules* (20.45 MPa) and *E. camaldulensis*(23.74 MPa). With increases of stand growth age the values of MOR showed decreasing trend. A similar trend was observed in Figure 2b for MOE, where boards obtained from nine years-old *E.saligna* had higher MOE (4223.56 MPa) values than boards from *E. globules* (2704.48 MPa) and *E. camaldulensis* (2377.95 MPa).

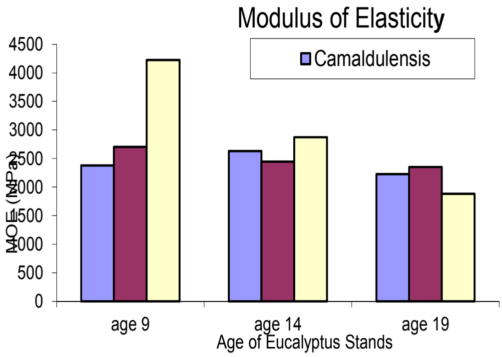

Figure 2b. Effects of species and age on MOE.

With increases of stand growth age the results of MOE decreased in all species. This could be happen due to the mass of eucalyptus woody substance compacted to form a board of higher density at old growth age. This condition resulted in an increased mass per unit volume of wood available to distribute stress and increased contact between the particles that resulted in improved bonding (Vital *et al*., 1974; Seyoum *et al.*, 2006).

The results of this experiment showed that harvesting *E. saligna* at 9 year-old growth age can give the highest MOR and MOE values. On the other hand boards made from *E. camaldulensis* showed the lowest MOR and MOE values in all age-groups. Based on the results of this experiment harvesting *E. saligna* and *E. globules* at the age of 9 years-old can give strong boards for structural and furniture applications because it has low thickness' swelling values or high dimensional stability.

Table 1. Summary of different variables of the three studied eucalyptus species

Species	Measured variables	Age of stands (years)		
		9	14	19
Eucalyptus saligna	Board Density (kg/m^3)	438.45[33.05]	464.43[38.50]	468.99[23.07]
	MOR (MPa)	27.48[3.71]	20.19 [4.67]	13.13[3.63]
	MOE (Mpa)	4223.56[889.00]	2871[792.60]	1882[535.49]
	Thickness swelling (%)	10.30[2.11]	11.42[1.76]	14.58[]1.89
	Water absorption (%)	32.78[7.41]	45.92[5.96]	51.73[4.99]
Eucalyptus globules	Board Density (kg/m^3)	476.03[33.34]	465.78[41.57]	470.24[23.72]
	MOR (MPa)	20.45[3.83]	17.9[3.81]	16.55[3.67]
	MOE (Mpa)	2704.48[597.77]	2446.77[610.29]	2350.61[489.85]
	Thickness swelling (%)	19.88[1.84]	18.01[1.39]	17.79[1.99]
	Water absorption (%)	72.16[7.63]	66.88[7.57]	66.7[8.73]
Eucalyptus camaldulensis	Board Density (kg/m^3)	694.35[20.33]	696.17[21.38]	757.17[21.99]
	MOR (MPa)	13.74[3.19]	15.18[3.86]	13.29[3.19]
	MOE (Mpa)	2377.95[956.78]	2632.77[545.06]	2229.51[950.78]
	Thickness swelling (%)	14.91[2.43]	17.05[2.46]	16.73[2.44]
	Water absorption (%)	53.75[7.49]	56.32[6.43]	58.57[6.40]

Note: Numbers in parentheses are standard deviations.

Thickness swelling and water absorption

Species and age variability had significant impacts on dimensional stabilities of particleboards. As depicted in Figure 3a and 3b boards made from old age stands had high thickness swelling and water absorption than those made from young stands.

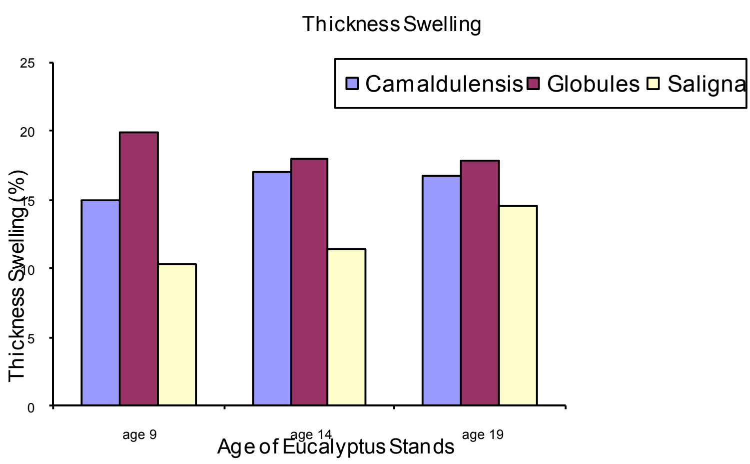

Figure 3a. Effects of species and age on thickness swelling

In 24 hours water-soak test, boards made from *E.saligna* had low thickness swelling (10.3%, 11.42%, 14.58%, respectively) in all age groups of timber stands. Next to *E. saligna, E. camaldulensis* showed lower thickness swelling than *E.globules*. The results of this experiment indicated as boards obtained from *E. saligna,* and *E. camaldulensis* are more stable than boards made from *E.globules.* Similar results were observed on water absorption in Figure3b.Boards made from all age groups of *E. saligna,* had the lowest water absorption than the other two species.

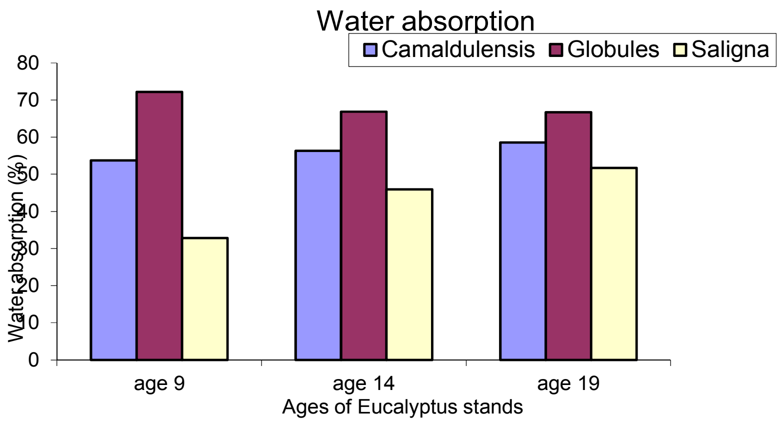

Figure 3b Effect of age and species on water absorption.

Water entry into the higher density *E.camaldulensis* boards occurred at a slower rate due to the decreased porosity and the increased wood material. On the other hand, *E.globules* showed the highest water absorption. This could be happen due to several factors. One of the factors could be undoubtedly, related to spring back behavior of the *E.globules* boards. The spring back increases with increasing board density due to the release of residual compressive stresses imparted to the board during the pressing of the mat in the hot press (Naresworo and Naoto, 2000; Seyoum *et al.*,2007). In general, species variability had significant impacts on thickness swelling and water absorption properties than age variability.

Conclusions

The manufacture of three-layered particleboards from 9 and 14 year- old *E. saligna* and *E.globules* appears to be technically feasible in terms of static bending properties. Boards made from all age groups of *E. saligna* had stable dimensional stabilities than the other two species. To improve the dimensional stability of *E. globules* boards the amount of resin consumption should be increased during board manufacturing.

In general particleboards made from 9 year-old *E.saligna* gave higher strength, stiffness and dimensional stability compared to *E. globules* and *E. camaldulensis.* Therefore, it is possible to conclude that *E. saligna* harvested at 9 year-old growth age is more suitable raw material for the production of particleboard.

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Influence of Growing Locations and Culm Positions on Physical and Mechanical Properties of Lowland Bamboo (*Oxythenantera abyssinica*)

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Introduction

The monotypic genus lowland bamboo, *Oxythenantera abyssinica* (A. Richard) Munro is the most widely distributed bamboo in western lowlands of Ethiopia and over 850,000 ha of bamboo resource in the country is covered by this bamboo. *O.abyssinica* is a clumping (sympodial) type with solid culm at maturing age. It has an average culm diameter of 5 cm and is 7 m high. This species grows at an elevation of between 1000 to 1800 m above sea level and is widely distributed in lowland areas of the country. It grows naturally in warm climates with average temperature of 35^{o} C and mean annual rainfall between 900 and 1400 mm (Anonymous, 1997).

The average stocking of bamboo forests of this species is 8000 culms/ha and the average annual increment of culm oven-dry matter is 8.5 tones/ha (Anonymous, 1997). This bamboo is a valuable economic plant, because its culm is using for various types of construction and furniture applications. Due to shortage of other timber resources this bamboo is now days became commercial and substantial product in the country.

O.abyssinica culms are widely marketed because they have been used for ceiling frame, walls and roofs of lodges, construction and furniture making due their straight, strong and solid culm characteristics. However, the qualities of bamboo poles harvested from different growing locations are not the same. There is a lack of information on physical and mechanical properties of these bamboo culms. Evaluating properties and identifying growing locations are essential to utilize this bamboo for construction purposes. As several other researchers proved growing locations have significant effects on wood and bamboo properties due to environmental variations (Abd.Latif, 1996). AsWiemann and Williamson (2002) reported geographical locations (altitude and temperature) where the wood grows may have a great influence on basic density of wood. Moore *et al*., (2009) also reported, elevation has been found most important factor affecting variation in wood properties between sites of

Sitka spruce plantations growing in northern Britain.The influence of growth conditions on bamboo has been found marked differences in technological properties exist among individual culms from the same stand and even more among those from different localities. For example, the bamboo species *Gigantochloa pseudoarundinacea*, growing on the slope, showed higher specific gravity, bending and tensile strength than those growing in the valley (Soeprayitno et al., 1987).

Several studies have demonstrated that the physical and mechanical properties of bamboo mostly depend on the species, site, silvicultural treatment, harvesting season, felling age, density and position of the sample with respect to the height (Espiloy,1992; Lee et al.,1994; Abd. Latif, 1996; Liese and Weiner, 1996).Based on these concepts, the objective of this study was to investigate the influence of growing locations and culm portions on selected physical and mechanical properties of *O. abyssinica*.

Materials and Method

Sample collection site description

O. abyssinica culms used in this study were harvested from three major lowland bamboo growing sites (hereafter, locations) in Ethiopia namely Asosa, Dedesa and Pawe. Geographical location, annual temperature, annual rainfall and latitude of these areas are shown in Table1.

Table 1. Geographical location and climate of three major *O. abyssinica* growing areas

Site	Location		Temperature (^{o}C)	Elevation (m)	Precipitation (mm)
	Latitude	longitude			
Asosa	10.03 °’ N	34° 59’ E	14-27	1590	950-1208
Dedesa	9. 10°’ N	35 ° 47‘ E	13-24	1845	1400-1703
Pawe	11.09 °’ N	36.03‘ E	16-32	1050	1200-1585

Source: Anonymous, 1988.

Sample preparation for physical and mechanical properties

Four years old bamboo stands were selected from each growing location for this study. The age of culms was estimated based on visual inspection of color and sheaths in culms. This was done by experienced field personnel’s’ familiar with this bamboo species. Twelve representative culms from each growing location and a total of 36 culms were harvested in January 2009. Based on the minimum solid culm wall thickness at the top of bamboo stem, the merchantable length of the culm was fixed at 7.5 m. Then, each culm was cross-cut into 2.5 m equal portions, namely bottom, middle, and top portions.

Replicates of green samples with the dimension of 3 cm length were taken from the middle parts of the first internodes of each portion to investigate basic density and moisture variation along the culm height and among growing sites. Samples from all portions were dried by kiln drier to 12% moisture content before testing. From each section, two 30 cm long pieces, one of them with the nodes at the midsection and the other without nodes were cut for testing mechanical properties. Then, all 30 cm long pieces were split into halves and minimum planing was done on inner and outer perimeters to make the samples rectangular. Eighteen samples from each culm portion and a total of 162 samples from three growing locations were prepared for modulus of rupture (MOR) and modulus of elasticity (MOE) testing. Samples with 300 mm length by 25 mm width by 6 mm thickness were used for bending test. A total of 162 samples (50 mm long, 13 mm wide and 6 mm thick) were prepared for compression parallel to the grain (hereafter, compression strength).

Bending and compression tests were conducted following the ISO 3133 (1975) and ISO 3387 (1976) standard procedures, respectively. After selecting bending specimen, a specimen with 10 mm width by 50 mm length was cut from each portion for measuring of percent shrinkage values in tangential and radial directions according to ISO 4469 (1981) standard procedure. Due to negligible differences of measurements, the results of longitudinal shrinkage were not reported in this paper.

Experimental design and analyses
Completely randomized design (CRD) with factorial experiment was used to conduct this experiment. The analysis of variance (ANOVA) also used to evaluate the influence of growing locations and culm height on physical and mechanical properties of *O. abyssinica.* Further analysis of the means was carried out by mean separation using Duncan mean comparisons.

Result and Discussion

Basic density and moisture content
This study has shown that there is considerable variation in density and initial moisture content of *O. abyssinica* grown in three locations and three culm heights. The analysis of variance (Table 2) indicated that there is high significant differences ($P<0.01$) in basic density and moisture content among

sites where the bamboo grows. The interaction effects of culm length with bamboo growing locations had high significant effects (P<0.01) (Table 2) on basic density and moisture content.

Table 2. Summary of analyses of variance on physical properties of *Oxythenantera abyssinica*

Source of variation	DF	Mean square and statistical significances	
		Density	Moisture content
Site	2	0.138**	8414.81**
Height	2	0.014**	268.57**
site x height	4	0.004**	187.32**

*Note: ns- not significant at p<0.05, *Significant at p<0.05, **highly Significant at p<0.01*
X-stands for interaction

Table 3.The average results of basic density and green moisture content from 3 culms height and three growing locations

Measured variables	sites	Culm portion			Average culm density and moisture content
		Bottom	middle	top	
Density (Kg/m3)	Asosa	536.58[0.01]	552.50[0.01]	516.75[0.01]	535.28
	Dedesa	609.33[0.01]	619.33[0.01]	614.58[0.00]	614.41
	Pawe	648.00[0.02]	700.91[0.09]	623.83[0.01]	657.58
Moisture content (%)	Asosa	90.85[3.08]	86.67[2.93]	98.38[5.17]	91.97
	Dedesa	65.66[1.52]	64.61[1.80]	65.20[1.77]	65.16
	Pawe	70.52[6.91]	62.24[10.33]	64.71[4.79]	65.82

Note: Numbers in parentheses are standard deviations.

As indicated in Table 3 the highest mean basic density (700.91 kg/m^3) was observed at the middle portion of culms grown in Pawe, while the lower (516.75 Kg/m^3) was at the top portion of culms grown in Asosa. In general, the basic density of this bamboo showed increasing trend from bottom towards the middle portion and then decreased at the top Regardless of culm height, the average density of O. *abyssinica* for three growing locations was in the range of 532.27 Kg/m^{3}to 657.58 vg/m^3. On the other hand, initial moisture content showed decreasing trend from bottom towards the middle portion and then increased at the top. Significantly higher moisture content (98.38 %) was observed at the top portion of culms grown in Asosa while the lower (62.24 %) was at the middle portion of culms grown in Pawe. As indicated in Table 3, culms grown in Pawe had high mean basic density (657.58 Kg/m^3) than culms grown in Asosa (535.28 Kg/m^3) and Dedesa (614.41Kg/m^3).

High annual temperature (32^oC), precipitation (1585 mm) and low altitude (1050 m) may be responsible for high amount of cell wall substance per unit volume of bamboo grow in Pawe. From the results obtained here (Table 3), it is apparent that there is a wide range of density and moisture variation among bamboo growing locations. As Wiemann and Williamson (2002) and Moore *et al*., (2009) reported geographical locations (altitude and temperature) where the wood grows may have great influence on basic density of wood. Evaluating basic density and initial moisture content of culms among three major bamboo growing areas has an important implication for determining the end uses of this bamboo species for various applications.

Mechanical and shrinkages properties of *O. abyssinica*

Evaluating mechanical properties of bamboo help to analyze is culm's behavior when it subjected to loads. Static bending test is the key parameter for engineers when designing structures for the serviceability. Therefore, data on bamboo strength properties obtained from this study may used to identify best growing location where high quality culms can be harvested. The analysis of variance shown in Table 4 indicated bamboo growing locations and culm height as well as their interaction effect had high significant (p<.0.01) effects on MOR, MOE, compression and tangential shrinkage except the interaction effect of MOE which had significant effect at ($p<0.05$) level. However, growing location and culm height did not show significant effect on radial shrinkage but their interaction had high significant ($p<0.01$) effects (Table 4).

Table 4. Summary of the analyses of variance on mechanical and shrinkage properties

Source of variation	DF	Mean square and statistical significances				
		MOR	MOE	Compression	Tangential shrinkage	Radial shrinkage
Site	2	14671.79**	1.39E-7**	2272.08**	64.03**	6.17ns
Height	2	10602.90**	2.31E-7**	5668.72**	20.72**	4.37ns
Site x height	4	2753.82**	1..58E-7*	745.86**	17.93**	14.85**

*Note: ns- not significant at p<0.05, *Significant at p<0.05, **highly Significant at p<0.01*

Influences of culm position on mechanical and shrinkage properties

The mechanical properties and shrinkage results of three culm's positions with nodes and without nodes obtained from three bamboo growing locations are presented in Table 5.

Table 5. Average strength and shrinkage values of culms with nodes and without nodes at ---% moisture content from three height portions

Measured variables	Locations	Culm portion without nodes			Culm portion with nodes		
		Bottom	middle	top	bottom	middle	top
Modulus of rupture (MPa)	Asosa	172.86[22.07]	172.66[23.71]	157.50[15.93]	151.27[35.45]	164.11[19.98]	142.33[26.05]
	Dedesa	190.16[18.99]	172.66[26.91]	165.66[19.03]	113.94[38.03]	126.77[20.85]	126.38[13.99]
	Pawe	144.08[21.20]	155.55[17.03]	113.94[53.77]	120.94[26.87]	132.22[122.18]	124.22[18.23]
Modulus of elasticity (MPa)	Asosa	14534.95[2326.13]	13550.73[2025.41]	11664.34[1991.82]	12953.63[2968.12]	14150.77[1977.68]	10668.96[2050.81]
	Dedesa	12206.87[1308.29]	11553.04[1295.91]	10995..91[1840.62]	11886.67[3993.06]	13280.09[2302.94]	12103.79[3849.69]
	Pawe	11626.72[4548.52]	11257.22[1917.15	10911.62[2174.93]	9313.58[1640.07]	9842.37[2061.50]	8140.37[2680.34]
Compression parallel to the grain (Mpa)	Asosa	73. 10[16.74]	84.06[13.06]	56.16[11.66]	43.41[6.88]	49.11[13.51]	53.29[15.58]
	Dedesa	78.23[11.57]	79.16[8.35]	76.35[6.12]	52.39[10.80]	62.16[10.12]	48.52[6.51]
	Pawe	65.32[18.68]	73.13[11.34]	51.76[22.21]	52.15[7.43]	35.51[6.86]	51.71[7.65]
Radial shrinkage (%)	Asosa	9.66[1.79]	9.06[1.87]	8.60[2.79]	10.39[2.72]	10.30[4.97]	8.44[1.88]
	Dedesa	6.64[1.58]	6.95[1.69]	9.61[3.37]	6.35 [2.49]	7.58[2.85]	8.05[4.67]
	Pawe	6.41[2.79]	8.76[3.03]	7.04[2.82]	8.79[2.64]	10.97[2.58]	7.85[2.07]
Tangential shrinkage (%)	Asosa	8.20[1.75]	7.04[1.63]	6.54[1.48]	7.98[1.98]	7.49[1.72]	5.79[2.52]
	Dedesa	5.93[0.99]	6.21[1.91]	6.69[1.70]	6.37[0.64]	7.47[2.02]	6.87[3.96]
	Pawe	6.14[1.81]	5.75[4.29]	7.34[2.07]	6.67[1.85]	9.38[2.90]	6.38[1.61]

Note: Numbers in parentheses are standard deviations

As indicated in Table 5 culms portion had significant effect on MOR values. Culms obtained from Asosa and Dedesa had showed a decreasing trend of MOR from bottom towards top portions. The results of MOR for culms obtained from Pawe increased from bottom to middle portion and decreased at top. Similarly, the MOR results of culm with nodes from all portions increased from bottom to middle portion and decreased at top. In addition to this, the presence of nodes significantly decreased the MOR values, especially in the bottom portion of the culms from 12% to 60%).

At 12 % moisture content, significantly higher MOR (190 MPa) was found in the bottom portion of culms obtained from Dedesa while the lowest MOR (114 MPa) was observed in the top portion of culms from Pawe. Regardless of growing locations, culms portions and the presence of nodes, the MOR values of O. *abyssinica* in this experiment falls within the range of 114 MPa to 190 MPa.

Culm without nodes showed decreasing trends of MOE from bottom towards the top portions On the other hand, the results of MOE for culms with nodes increased from bottom to middle portion and deceased again at the top. The presence of nodes had insignificant effect on the MOE values. Regardless of growing locations, culms portions and the presence of nodes, the MOE values falls within the range of 8140 MPa to 14535 MPa. Larger diameter and length of fiber might be responsible for high values of MOR and MOE in bottom and middle portions of *O.abyssinica*. Bamboo has large sizes of fiber dimension in the bottom portion of the culms (Liese, 1985; Liese and Weiner, 1996 and Seyoum, 2009).

Compression strength for culms without nodes from all growing locations increased from bottom to middle portion and deceased on the top portion again (Table 5). On the other hand, culms with nodes showed inconsistent compression results along the height. Generally, it's observed in this experiment that the presence of nodes highly decreased the compression strength of the culms. The presence of nodes reduced the compression strength from 21% to 51% in bottom and middle portions. For culms without nodes, the highest values of compression strength were observed in the middle portion. Regardless of culms position and the presence of nodes, compression strength obtained in this experiment falls within the ranges of 36 MPa to 84 MPa. Long fiber length and thick fiber wall thickness might be responsible for high values of compression strength in the middle and bottom portions of the culms.

As indicated in Table 5 the results of radial shrinkage showed inconsistent variation along the culms portion. The presence of nodes slightly increased radial shrinkage culms obtained from Asosa and Dedesa. However, for culms obtained from Pawe the presence of nodes increased the radial shrinkage from 12% to 37%. Similarly, the tangential shrinkage also showed inconsistent variation along the culms portion. High radial shrinkage values were observed than tangential shrinkages in this experiment. The distributions and sizes of vascular bundles in the outer part of bamboo wall than the inner parts may responsible for higher radial shrinkages than tangential. According to Liese (1985) the inner part of bamboo wall has more parenchyma and conducting cells which are responsible for low shrinkage. Regardless of culms position and the presence of nodes, the radial shrinkage obtained in this experiment falls within the range of 6.41% to 11% and the tangential shrinkage falls within the range of 5.75% to 9.38%.

Influences of bamboo growing locations on mechanical and shrinkage properties

Bamboo growing locations had significant effect on mechanical properties and shrinkage. As indicated in Table 6, culms obtained from Dedesa had high MOR values (176 MPa) than culms obtained from Asosa (168 MPa) and Pawe (138 MPa).

Table 6. Average mechanical and shrinkage values of *O. abyssinica* culms from three bamboo-growing locations

Measured variables	Locations	Culm without nodes	Culm with nodes
Modulus of rupture (MPa)	Asosa	167.67	157.57
	Dedesa	176.16	122.63
	Pawe	137.86	125.79
Modulus of elasticity (MPa)	Asosa	13250.01	12591.12
	Dedesa	11601.39	12423.52
	Pawe	9098.77	11265.19
Compression parallel to the grain (MPa)	Asosa	71.11	48.60
	Dedesa	77.91	54.35
	Pawe	63.40	46.45
Radial shrinkage (%) from green to ----% moisture content	Asosa	9.11	9.71
	Dedesa	7.73	7.32
	Pawe	7.40	9.20
Tangential shrinkage (%) from green to ----% moisture content	Asosa	7.26	7.08
	Dedesa	6.28	6.90
	Pawe	6.41	7.47

The presence of nodes reduced the value of MOR 6%, 9% and 30% respectively for culms from Asosa, Pawe and Dedesa. On the other hand, culms from Asosa exhibited high modulus of elasticity (13,250 MPa) than culms from Dedesa (11,601MPa) and Pawe (9,099 MPa). The presence of nodes had insignificant variation for culms from Asosa and Dedesa. However, for culms form Pawe it reduced the MOE value to 24%. Lower MOR and MOE strength properties were observed on clms from Pawe compared to the other two sites. Similarly, culms from Pawe had lower compression strength (63 MPa) than culms from Dedesa (78 MPa) and Asosa (71 MPa). On the other hand, the presence of nodes reduces the compressive strength from 27% to 32%. The lower strength properties of bamboo from Pawe compared to other two sites may be attributed to differences in altitude, temperature and rainfall of this specific site (Table 1).

It was noted in several studies that the geographical locations where the bamboo grow may have a great influence on its properties. As Wiemann and Williamson (2002) , Moore, *et,al.,* (2009) and Harris (1996) reported altitude, annual rainfall, temperature and soil type are the major factors for wood properties variability. The lower altitude (1090 m) and high temperature (16-32 ^{o}C) of Pawe may have impact to increase the density of culms in Pawe. These conditions might have negative influence for the culms fiber lengths increment in this site. The quality of fiber sizes, especially fiber length may responsible for the reduction of strength properties of the culms obtained from Pawe than the other two sites. The other factor for strength variation in each growing location might be the soil variability. According to FAO (1984) reports, the three bamboo growing locations have similar soil types such as vertisols, chronic and orthic luvisols, acrisols, and calcaric and eutric fluvisols.

The presence of nodes increased the radial shrinkage to 6% and 20% for culms from Asosa and Pawe and also increased to 9% and 14% tangential shrinkage for culms from Dedesa and Pawe. In general, the radial shrinkage showed 6% to 27% higher values than the tangential shrinkages for all sites. On the other hand, culm with nodes from Pawe had high tangential shrinkage (7.47%) than the other two sites. This may happen due to high density or amount of cell wall substance per unit volume and the distribution of vascular bundles of bamboo grown in Pawe.

Selected mechanical properties and shrinkage values of *O.abyssinica* were compared with some bamboo species to ranks the results obtained in this experiment with other findings (Table 7).

Table 7. Comparison of mechanical and shrinkage properties of *O.abyssinica* with some bamboo species

Species	Density (kg/m^3)	Mechanical properties			Shrinkage properties	
		MOR (N/mm^2)	MOE (N/mm^2)	Compression parallel to the grain (N/mm^2)	Tangential shrinkages (%)	Radial shrinkages (%)
Bambusa tulda	640	120	12618	64	-	-
Dendrocalamus giganteous	730	51	9584	49	-	-
Bambusa vulgaris	790	76	11720	47	22.45	-
Melocanna becciferia	817	56	14617	49	-	-
Bambusa nutan	*693*	*85*	*12315*	*70*	-	-
Phyllostachys bambusaidea	-	103	10687	42	9.25	18.21
Bambusa burmanica	780	103	11655	52	-	-
Oxythenantera abyssinica (culm with nodes from Asosa)	535	158	12591	49	7.08	9.71

Source: Mansur, 2000.

The MOR of *O. abyssinica* was higher by 68%, 52% and 35%, respectively than *Dendrocalamus giganteous, Bambusa vulgaris* and *Phyllostachys bambusaidea.* Similarly, the MOE values were also higher by 24%, 11% and 15%, respectively. On the other hand, *O.abyssinica* showed equal compression value with *Dendrocalamus giganteous,* higher by 4% and 14% than *Bambusa vulgaris* and *Phyllostachys bambusaidea,* respectively. *O. abyssinica* showed less tangential and radial shrinkages than the above mentioned bamboo species. Due to its high strength properties and dimensional stabilities *O.abyssinica* can be used for structural applications in construction sector and furniture making.

Conclusion

Identifying of bamboo properties variations among growing locations is helping to manipulate the desirable characteristics of bamboo and its utilization. The results of strength values in this experiment revealed that culms obtained from Asosa and Dedesa locations has high MOR, MOE and compression strength than culms from Pawe. Culms from Dedesa have lower shrinkage value than the other two locations. The presence of nodes was highly (27-32%) decreased the value of compression strength. Based on these results, it's possible to recommend that removing nodes at the end of culms when culms used as column or attached with beam can give high compression strength. In general, the presence of nodes reduced MOR and shrinkage values.

However, nodes have insignificant impact on MOE values of culms from Asosa and Dedesa. Based on the results of *O. abyssinica* and comparison with other bamboo species, it is possible to recommend that culms of this bamboo species can be used for structural applications and furniture making due to its has high strength properties and less shrinkage values.

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Increasing the Service Life of Bamboo Culms as Construction and Furniture Material by Controlling Biodeterioration and Rational Utilization

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Introduction

Bamboo species according to archeological evidences appeared 200 million years ago on this planet and have diverse socio-economical, environmental and ecological importance (products and services) at local, national, regional and global levels. It is a perennial plant, constitutes about 1500 species and provides more than 1500 industrial, construction, other versatile uses and services. No plant is known in the tropical zone, which could supply so many technical advantages as bamboo. It has been in use since 4000-5000 years ago. Among bamboo's environmental and socio-economical desirable characteristics are its wide distribution, availability, rapid growth and renewability, easy handling and desirable properties, environmental-enhancing resource, source of versatile and useful products and means of income for millions of people. Bamboo is a mystical plant as a symbol of strength, hardness, lightness, flexibility/elasticity, tenacity, endurance and compromise together with its availability and the ease with which it may be split into narrow strips for versatile applications (Ghavami, 2001; Anonymous, 2008a). The global bamboo market generates about $12 billion/year for more than 600 million people that can grow to more than $20 billion in 2015 (Ghavami, 2001; Ahmad and Kamke, 2003; Sastry, 2004; Bowyer et al., 2005; Anonymous, 2008; Anonymous, 2010a,b).

Bamboo has narrow stem and numerous internodes, flammability, it easily splits/cracks and shrinks, has low durability and prone to insects and fungal attack as shortcomings. In order to, make efficient use of bamboo, it is necessary to adopt modern processing and rational utilization techniques, including preservation of culms, proper drying (seasoning) and other bamboo-based products. Bamboo has different extractives such as resins, tannins, waxes and inorganic salts and higher alkaline extractives such as ash and silica contents, however, none of the extractives in bamboo have enough toxicity to reveal any natural durability but the presence of large amounts of starch (carbohydrate), hemi-cellulose and excess moisture makes it more attractive, ready food source, highly susceptible and vulnerable from the time of harvesting.

More than 40% of bamboo destroyed due to biological agents' damage during its utilization and storing in untreated conditions (Salam and Deka, 2007). Bamboo's susceptibility to biodeteriorating agents and physical deterioration, lack of appropriate processing, protection and rational utilization technologies are among the major constraints hindering sustainable development, processing, value addition, marketing and rational utilization of the bamboo resource (Tomalang et al. 1980; Liese, 1992; Kumar et al., 1994; Jayanetti and Follet, 1998; Kumar and Dobriyal, 1988; Yumus-Uzzaman, 1998; Kassahun Embaye, 2000; Chen et al. 1985 cited in Li, 2004; Dransfield and Widjaja, 2004; Li, 2004; Wong, 2004; Bowyer et al., 2005; Salam and Deka, 2007; Hall and Inada, 2008; Inada and Hall, 2008).

The natural durability of bamboo depends upon species, climatic conditions and the place/ environment (above ground under cover, ground and soil contact and marine), where it has been utilized. In Ethiopia, ceilings of the King Minilik II Palace at Entoto in Addis Ababa were constructed during 1889 may be from untreated split bamboo culms have been still intact by biodeterorating agents (personal communication and observation). Termites, beetles, borers and fungi independently and/or jointly destroy untreated bamboo culms within one month to three years duration of harvest, storage and utilization, while preserved bamboo based on intended place of utilization will give a service life of 10-40 years, an increment of 4-10 times compared to the untreated bamboo (Tamolang et al., 1980; Liese, 1980 cited in Kumar et al., 1994; Liese, 1985; Willeitner and Liese, 1992; Kumar et al., 1994; Janssen, 1995; Younus-Uzzaman, 1998; Islam et al., 2002).

Seasoned stems of *Y. alpina* used in construction and fencing are susceptible to infestation by the powder-post beetle *Dinoderus minutus*. However, in Demoractic Republic of Congo, stems considered durable, houses and fences made from said to last for more than 20 years (Hall and Inada, 2008). Seasoned stems and fences made from the stems of *O. abyssinica* are susceptible to termite and borer attacks (Inada and Hall, 2008).

The most important group of biodeterorating agents that damage forest products (wood and bamboo) belongs to the orders Isopetra (termites-wood and ground dwelling), Coleoptera (beetles) and the three classes of fungi/microorganisms namely Ascomycetes (soft rots and in some cases cause blue stain), Bascidiomycetes (brown -and white rots main agents of decay) and Deuteromycetes-fungi imperfecti (mold, staining and in some cases cause soft rots) (Nicholas, 1985; Groves, 1990; Shrivastava, 1997; Eriksson et al., 1990 cited in Adane Bitew, 2002).

Subterranean pest genera of wood and bamboo based structures is subfamily Macrotermitinae that include the species Macroterms, Odonototerms, microterms, Pseudacanthoterms and Ancistroterms where the 1st three are fungus growing termites. Subterranean termites have a foraging gallery of up to 50 m distance and 3 m depth (Wood, 1991; IOMC, 2000). Termites cause more than $3 billion of damage per year (IOMC, 2000). Subterranean termites are the most widely distributed species and credited with 95% of all the termite damages (Titmuss and Richards, 1971). Termites, fungi and other microorganisms have great role in nutrient recycling by decomposing wood and other plant material (Groves, 1990; Nicholas, 1985; IOMC, 2000). Decay is by far the most serious kind of microbiological damage where much of it causes structural failures due to fungal discoloring and destroying (Nicholas, 1985).

Bamboo (*Yushania alpina* and *Oxytenantheria abyssinica)* has been widely distributed in Ethiopia and provides construction, fencing, food, fodder, household utensils, handicrafts, furniture, artisan, musical instruments, flooring and versatile industry materials, environmental benefits, other products, structures and services (von Breitenbach, 1963; Liese, 1985; EFAP, 1994; Phillips, 1995; LUSO Consult, 1997; Melaku Abegaz and Addis Tsehay, 1988; Kassahun, 2000; Ensermu Kelbessa, et al., 2000; Sisay Nune, 2001; MacLachlan , 2002; Getachew Desalegn and Wubalem Tadesse, 2004; Melaku Abegaz et al., 2005; Tesfaye Hunde, 2006; Wang, 2005-2006; Arsema Andargatchew, 2008; Hall and Inada, 2008; Inada and Hall, 2008; Yigardu Mulatu and Mengistie Kindu, 2009; Seyoum Kelemwork, 2011).

Bamoo is one of the forest green gold/valuable resources of Ethiopia such as timber, coffee, gum-resins, species and other non-timber forest products (NTFPs) which are not still properly managed, taped and utilized. Rural people largely depend on raw bamboo culms for the above stated uses. In some areas of Ethiopia such as Injibara, Tikure Inchini and Hagere Selam, the income from selling of bamboo culms out ways more than twice of the crops from the same plot of land

and eucalyptus wood lots (Personal communication) while framers of the Shedem Kebele/locality in Bale zone generate 47% of their annual income from harvesting and selling of bamboo culms (Aresema Andargachew, 2008).

Some of the current challenges of bamboo resource in Ethiopia: (i) despite its wide rural significance, bamboo remained neglected in the forestry and agricultural sectors, INBAR recently included *O. abyssinica* among 38 priority bamboos of economic importance (Inada and Hall, 2008), (ii) there exists very limited local market for bamboo handicrafts processed manually, (iii) there exists only a few specialized enterprises that produce bamboo furniture, (iv) poor processing and low value addition (Wang, 2005-2006) though there are about 500 furniture producers in the country out of which 58 in Addis Ababa, (v) expansion of agricultural land, open grazing, settlements, fire and investments in other sectors, (vi) recently bamboo flowering has occurred in Ethiopia covering more than 85% of the lowland bamboo in all three zones of Benishangul Gumz and Awi zone of Amhara Regional States and 60% of highland bamboo in Dawro zone of Southern Nation and Nationalities regional state (Demissew Sertse et al, 2011) and (vii) biodeteriorating agents are among the major driving factors against bamboo groves, products and services. Biodeteroration of bamboo in Ethiopia is very fast (<1-2 years) and has economic significance. In some areas bamboo resources left to decay and degrade due to lack of proper management (Wang, 2005-2006) and utilization. Fast deterioration resulted in frequent harvesting that in turn imposed high pressure and depletion on the remaining stock.

In Ethiopia, for the evaluation, identification and control of termites and fungal damages on agricultural cops, range lands, timbers natural durability and performance of applied preservatives, there have been few research activities[1] on few timber species, protection measures and agroecological zones.

[1] - Subterranean termites, the most destructive type of termites attacking wood and other vegetation (*Termitidae*- 85% of the subterranean termite species attacking trees and wood, *Rhinotermitidae*-attacking tree stumps and logs and *Hodotermitidae*-attacking grass), fungi (brown, white - and- soft rots) such as basidiomycete fungi (*Armillaria mellea*), and powder-post beetles (*Dinoderus minutus*) considered as major causes of greatest threat to wood and bamboo based products and constructions, trees and plantations, bamboo species, agricultural crops (fruit trees, wheat, tef, maize, barley, sorghum, ground nuts, sugar cane, rice, etc) and rangelands in Ethiopia, which led to partial or complete abandoning of land and/or rebuilding in 2-5 years (Holmgren, 1963; Zawde Berhane and Yusuf, 1974; Nicholas, 1985; Wood, 1986; Melaku Abegaz and Addis Tsehaye, 1988; Cowie, et al., 1990; Wood, 1991; Abdurahman Abdulahi, 1991; Eaton and Hale, 1993; WUARC, 1995; Tsegay Bekele, 1996; Kassahun Embaye, 2000; Seyoum Kelemwork and Deribe Gurmu, 2000; Adane Bitew, 2002; MacLachlan et al, 2002; Getachew Desalegn et al., 2003; Getachew Desalegn et al., 2007; Ofgaa Djirata et al., 2007; Hall and Inada, 2008; Inada and Hall, 2008; Wubalem Tadesse and Getachew Desalegn, 2008; Getachew Desalegn, 2010; Getachew Desalegn and Alemu Gezahgne, 2010; Getachew Desalegn et al., 2010; Getachew Desalegn and Wubalem Tadesse, 2010; Behailu Kebede et al., 2011; Getachew Desalegn et al., 2012).

Current utilization of bamboo in the country has been limited mainly due to the stated shortcomings. There is no adequate information on bamboo culms natural durability, treatability-with-and- effective preservatives and other properties (here after characteristics) in the country. Strong strategies/measures are needed to protect and rationally utilize this versatile resource of the country. Applying proper seasoning, handling and effective preservation could be among the measures to be taken towards increasing its service life, value addition and rational utilization thereby reducing the high pressure encountered on the endangered tree species and bamboo itself. Therefore, it is imperative to protect wood/timber and bamboo products from biodegrading organisms (insects and fungi) by treating with the appropriate preservatives and application techniques (Willeitner and Liese, 1992; Shrivastava, 1997).

Protection measures research on bamboo was initiated as an important thematic and Regional Research area in Ethiopia and Kenya and implemented by their respective Research Institutes namely the Ethiopian Institute of Agricultural Research (EIAR) under Forestry Research Center (FRC)/Forest Products Utilization Research Case Team (FPURCT) and Kenya Forestry Research Institute (KEFRI). *Yushania alpina*, *Oxytenantheria abyssinica* studied in Ethiopia while *Yushania alpina* and *Dendrocalamus giganteaus* studied in Kenya.

However, the results in this paper include only the Ethiopian part, unless otherwise stated. In case of bamboo protection measures, this study could be so far the 1st practical attempt in Ethiopia. The hypotheses tested in brief were: (i) bamboo culms are naturally resistant/durability against all termites, beetles and fungal attack, (ii) bamboo culms are easily treatable with preservatives, and (iii) all preservatives are effective to increase durability and service life of bamboo culms, thereby bamboo-based structures and products will give long service life.

Therefore, the general objectives of this study were to investigate natural durability of *Yushania alpina* and *Oxytenantheria abyssinica* culms, effectiveness of preservatives and application techniques against biodeterorating agents and select appropriate protection measures that can enhance service life and rational utilization of bamboo and bamboo-based products products and structures. The specific objectives of this study were to (i) investigate natural durability and treatability of culms from the two bamboo species, (ii) evaluate effectiveness of preservatives and application methods against termites, beetles and fungi, and (iii) select durable bamboo species and effective protection measures. The focus of this article is on subterranean termites, beetles and fungal attack, natural durability of bamboo species and effectiveness of preservatives at four different agroecological zones and sites in Ethiopia.

Materials and Methods

Study sites

The study was conducted at four agroecological zones and field stations (graveyard sites), located in Addis Ababa, Bako, Adami Tulu and Pawe. In addition to field study, above ground/off-ground (non-ground contact) and accelerated decay (laboratory) tests were also conducted. All non-ground contact tests and lab treatability tests were carried out at FPURCT laboratory.

Test sites were located in hazardous areas of bamboo degrading agents (termites and fungi), where the bamboo resource and/or its demand is high and the population is in need of potential alternative materials, besides wood for different technical and aesthetic purposes.

Study species

Ethiopia has only two indigenous bamboo species with over one million ha. The highland bamboo (*Yushania alpina)* is estimated to cover over 300, 000 ha and the lowland bamboo (*Oxytenantheria abyssinica*) covers between 700, 000-850,000 ha (about 80%) of the bamboo covered land. The indigenous bamboo resources are the highest (67%) bamboo resource in Africa. Bamboo is widely distributed in the country and provides plenty of products and services (Kassahun Embaye, 2000; Melaku Abegaz et al., 2005; Tesfaye Hunde, 2006; Wang 2005-2006; Yigardu Mulatu and Mengistie Kindu, 2009). Currently, the resource base in some areas has been under high pressure (improper utilization) while in others under promotion (regeneration, development and management). Due to its fast growth and shortage of wood, bamboo become economic importance as alternative and/or supplementary to wood. There are also about 10 introduced bamboo species (*Bambusa balcoa, Bambusa vulgaris* var. Green, *Bambusa vulgaris* Striata*, Bambusa tudla, Dendrocalmus asper*, *Dendrocalmus brandisii, Dendrocalamus hamitoni*, *Dendrocalmus mebraceous,Guada amplexifolia* and *Phyllostachys pubescence*, etc.) (Tesfaye Hunde, 2008; Yigardu Mulatu and Mengistie Kindu, 2009; Alemu Gezahgne, et al., 2011; Seyoum Kelemwork, 2011) where some of them adapted and others still under investigation.

The two indigenous study species were *Yushania alpina* K. Schum *(*Arundinoideae) and *Oxytenantheria abyssinica* (A.Rich.) Munro

(Bambusoideae). The bamboo species have many Synonyms[2], Vernacular and common names[3]. *Y. alpina* occurs in scattered populations on mountains from southern Sudan and Ethiopia southwards to Malawi. It is frequently planted, e.g. in Ethiopia and Zimbabwe (Hall and Inada, 2008). *O. abyssinica* is distributed throughout tropical Africa outside the humid forest zone, from Senegal east to Eritrea, and south to Angola, Mozambique and northern South Africa.

Clump longevity of 30 years has been estimated for *O. abyssinica* in Sudan, but is less when mass flowering occurs and rhizomes die with the stems. Mass flowering of *O. abyssinica* occurs every 7 years (Uganda), 14 years (Zambia) or 20–21 years (Malawi), while sporadic flowering has been widely and frequently noted (Inada and Hall, 2008).

Bamboo's growth is more rapid than any other plant on the planet (about 1.2 m height in 24 hours period in Japan), even faster than Eucalyptus species, annually self renewable and harvestable if managed properly. Growth to full height and diameter is completed in one growing season of 2-3 months time. It has a short rotation life and maturity age of about 3-7 years for construction and furniture purposes that can be harvested in 3-5 years versus 10-50 years rotations for most softwood and hardwood tree species with annual biomass increment of 10-30% it attains versus 2-5% for trees (Liese, 1985; LUSO Consult, 1997; Rao and Rao, 1998; Kassahun, 2000; Ensermu Kelbessa, et al., 2000; Ahmad and Kamke, 2003; Sastry, 2004; Bower et al., 2005; Tesfaye Hunde, 2006; Kigomo, 2007; Biras and Tesfaye Hunde, 2009; Yigardu Mulatu and Mengistie Kindu, 2009; Anonymous, 2010a,b).

Bamboo is found at latitudes from 46°N to 47°S, with a mean annual temperature of 15-20°C and annual precipitation of 1000-1500 mm. Widely distributed from sea level to 4000 m and it covers about 22-25 million ha

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[2] - Synonyms of *Y. alpina* are *Arundinaria alpina* and *Sinarundinaria alpina*. Synonyms of *O. abyssinica* are *O. macrothyrsus* K.Schum., *O. braunii* Pilg., *O. borzii* Mattei. *Y. alpina* is hollow and monopodial (leptomorph–spreading/running form) while *O. abyssinica* the monotypic genus confined to Africa is solid and sympodial (pachymorph-clumping form) (Wolde Michael Kelecha, 1987; Kassahun Embaye, 2000; Hall and Inada, 2008; Inada and Hall, 2008; MacLachlan, 2002).

[3] - Vernacular and common names of *Y. alpina* are kerkeha (Amharic), shenbek'wa (Oromo Wellega), lemena, shikaro (Oromo Kefa), anini (Awi); African alpine bamboo, mountain bamboo (English), Bambou creux (French), Mianzi, mwanzi (Swahili). Vernacular names and common names of *O. abyssinica* are shimel (Amharic), betre (Sodo Guragie), arkay (Tigregna and Amharic), Shimela (Oromo), Savanna bamboo, Bindura bamboo, West African bamboo (English), Bambu africano (Portuguese), Mwanzi (Swahili) (Wolde Michael Kelecha, 1987; Kassahun Embaye, 2000; Hall and Inada, 2008; Inada and Hall, 2008; MacLachlan, 2002).

worldwide. This miracle plant benefits half of the world population and more than two billion people depend on it every day. The life of standing bamboo culm is about 10 years while the natural lifespan of a bamboo plant is more than 50 years for many species and over 100 years for many others (UNIDI, 2012). Bamboo having infrequent flowering characteristics at intervals of 20-120 years and then all culms will die and may regenerate later (Dransfield and Widjaja, 2004; Bowyer et al., 2005; Salam and Deka, 2007; Anonymous, 2010a,b).

Harvesting bamboo culms and sample preparation

Field reconnaissance surveys were done to some parts of the bamboo growing potential areas. The highland bamboo of Ethiopia was collected from the stated sites, specific localities and altitudes Hagere Selam (Meleya- Fincha Sefere) (3000 m), Injibara (Banja zone) (2300 m), Tikure Inchini (Woldo-Indie) (2300 m) and Masha (Soleschiu) (2400 m) sites and the lowland bamboo from Asossa (Komoshiga) (1540 m), Dedessa (Aba-Sena) (1500 m) and Pawe (Agricultural Research Center compound) (1200 m) (Figure. 2).

Matured bamboo stems (culms) were harvested during the dry season from matured (3-5 years old) bamboo stands with good morphological quality. Culms were selected and converted to sample billets/stakes of 1 m length and 3-5 cm diameter (top and bottom) along the culms merchantable height and transported while green to FPURCT laboratory. The Masha bamboo samples were all split by themselves during seasoning and thus used only for the split tests. The graveyard stakes were full size, 1m length and 3-5 cm diameter (top and bottom). The diameter of the samples (stakes) used for non- ground contact and laboratory tests was the same diameter as graveyard stakes and it had 0.5 m and 3 cm length, respectively.

All test stakes were free from visible defects that may affect uniformity of the test materials. The culms were trimmed to the final dimensions prior to each test. Aluminum stainless steel identification codes were used to differentiate the different treatments. The number of stakes was 18 per preservative treatment, 90 per graveyard site and a total of 360 stakes in case of graveyard tests, 126 for the non-ground contact and 72 for the accelerated decay laboratory tests.

Preservatives applied

The applied preservatives in this experiment were Tanalith water-borne commercial wood preservative, borax-boric acid, used motor oil, table salt, kerosene and the untreated control. Unlike copper chrome arsenate (CCA) preservative, Tanalith is free of chrome and arsenic ingredients. It is an environmental friendly preservative and having the same purpose and effect as the banned and limited use (since 30th June 2004) CCA preservative (Anonymous, 2005a, b; Archer and Lebow, 2006). Tanalith contains copper and organic azoles (CuAz) CA-B type co-biocides as active ingredients where copper contains 96.1% and tebuconazol 3.9%. Copper provides protection against most decay fungi and termites while the synthetic azole type co-biocide provides protection against copper tolerant organisms such as brown rot fungi (Anonymous, 2005b).

Among the properties that ensures Tanalith E's place as a forerunner in the waterborne class of preservatives are: (i) fixed in the timber and bamboo, offering long lasting protection, (ii) relatively low cost, (iii) no odor, either during or after treatment, (iv) non-tainting, can be used in direct contact with foodstuffs, (v) non-flammable, can be painted or stained after treatment, once dried to a suitable service, (vi) treated timber and bamboo is safe to handle and presents no health hazards (Anonymous 2005a). Anonymous (2005a), Tanalith E provides excellent performance against the whole range of destroying fungi and insects both in ground contact and non- ground contact for hazard class 1-4, gives service life of 15-60 years and in marine environments with hazard class of 5 guaranties for 15-30 years service life.

Toxicity of Tanalith E LD_{50} (oral, rat) > 500 mg/Kg, equivalent to 0.5 g/Kg and LD_{50} (skin, rat) > 2000 mg/Kg, equivalent to 2 g/Kg (Anonymous, 2005a). Pressure treatment of stakes with same machine and pressure as Tanalith has been applied to borax ($Na_2B_4O_7.10H2O$-disodium tetraborate decahydrate) - boric acid (H_3BO_3-Orthoboric acid) and water in a ratio of 1:1:54, respectively (Willeitnerand Liese, 1992; Kumar et al., 1994; Tesoro and Espiloy, 1988). Toxicity of boric acid, LD_{50} (oral, rat) is 2660 mg/Kg. The LD_{50} of table salt in rats is 3.75g/Kg (Anonymous, 2005a, b).

For the treatments with used motor oil, a mixture of Shell Rimula diesel oil 40 and Helix Ultra 40 engine oil was used (Jayanetti and Follet, 1998; Anonymous 2009). Crude table salt with ingredients of edible common salt, potassium iodized and permitted ant-caking agent was used besides Tanalith and used motor oil.

Experimental design and data analysis

In the study split-plot design under complete randomized (CRD) was used. The study consists of one main plot factor and two sub-plot factors. Origin of the species was treated as a main plot factor whereas preservatives and culm positions along height were the two sub-plot factors. The main plot has six levels and it includes stakes from Hagere Selam, Tikure Inchini, Injibara, Asossa, Dedessa and Pawe. The four study sites namely Addis Ababa, Adami Tulu, Bako and Pawe were taken as block factors for the combined analysis of data. Preservatives, one of the sub- plot factors has five levels and consists of (i) Tanalith at 3% concentration under solvent water, and (ii) Tanalith at 6% concentration under solvent water, (iii) a mixture of borax-boric acid under solvent water, (iv) a mixture of Shell Rimula diesel oil 40 and Helix Ultra 40 used motor oil, and (v) untreated control. Culm positions along height, the second sub- plot factor involved three levels, stakes from the bottom, middle and top sections. For the off-ground tests, in addition table salt and kerosene were included. The stakes for accelerated decay test were treated with Tanalith, borax-boric acid and used motor oil besides the control.

Treatments of bamboo stakes with preservatives

The natural durability and preservative effectiveness test categories in brief were: (i) outdoor, graveyard tests having external construction purposes, ground contact test with atmosphere and soil, (ii) indoor, above ground (non- ground contact) tests having furniture and internal construction purposes. Tests applied under cover but not in contact with atmosphere and soil, and (iii) laboratory/accelerated decay tests to obtain quick results so as to check and compare with graveyard and non-ground contact conditions.

All bamboo culms, except the culms used for sap displacement, i.e. green test, were air seasoned. The bamboo stakes for air seasoning were kept standing up right under shade for two months until an average MC of < 20% is achieved. Moisture content (%) = [(Initial weight - oven dry weight)/ (Oven dry weight of bamboo)* 100] and basic density (gm/cm^3) = [Oven dry weight (g)/weight of the displaced volume of water (cm^3)] (Panshin and de Zeeuw, 1980; ISO, 2001). Note that the weight of the displaced water is the volume of bamboo stakes.

Absorbation rate (Kg/m^3) of preservative solution was determined by subtracting saturated weight (Kg) of stakes after treatment from weight (Kg) of air seasoned stakes before pressure treatment and dviding by the volume of stake (m^3). Retention was determined by multipying the amount of preservative absored by the preservative strength/concentration (toxic capacity) and expressed in Kg/m^3. Extent of preservative permeability (penetration) was determined (FAO, 1994) by cross-cutting two discs from the treated stakes into 20 cm pieces, 20 cm inwards from both ends, measuring depth of chemical penetration and dividing the summation of maximum and minimum depths of penetrations (mm) to obtain mean penetration value.

Three preservative treatment application techniques, pressure, non-pressure (hot- and- cold dipping and soaking) and sap displacement methods were used to treat round and half split dry and green stakes separately. Prservative treatability (absorption and retention) of stakes were determined using the methods of Willeitner and Liese (1992) and FAO (1994).

Pressure treatment of stakes

Round and half split stakes were used for testing chemical treatability and permeability treatments. The chemical treatability and permeability of the study species were determined using pressure application technique of the Tanalith and borax-boric acid preservatives.

Two chemicals, Tanalith (at 3% and at 6% concentrations) and borax- boric acid (1:1 ratio) were separately used for pressure tests. Sweden brand Rentokil laboratory size Impregnation Machine was used for the pressure treatment of stakes. Then, the stakes were removed out from the machine and air seasoned for a week to allow fixation of the preservative and solvent evaporation.

Laboratory accelerated decay test

This test was carried out on 2x2x3 cm round blocks (ASTM, 1999) in Kenya on impregnated bamboo blocks at FPURCT laboratory (Ethiopia). In fungus inoculation test, brown rot fungus knows as *Wolfiporia cocos* (formerly *Poria cocos*) was used. An inoculum of 5 mm was taken from culture plates, inoculated on the soil and then bamboo stakes were placed on top of it. The experiment took three months.

The two aspects assessed from the accelerated decay test were: (i) natural resistance/durability of bamboo culms to fungal infestation, and (ii) fungicidal effectiveness of preservatives. Evaluation was carried out based on visual examination and percentage loss in weight.

Hot-and-cold dipping treatment

For the hot-and-cold dipping tank atmospheric pressure treatments, stakes were submerged in separate dipping tanks containing used motor oil and table salt solution and both gradually heated to 90°C. The test stakes of *Y. alpina* and *O. abyssinica* were kept in the tank for 30 minutes and one hour, respectively. The stakes were allowed to cool for 24 hours.

Non-pressure treatment of stakes

Soaking treatments

For soaking treatment air seasoned round and half split stakes of *Y. alpina* and *O. abyssinic*a were soaked in a drum containing kerosene to a length of 30 cm from the bottom portion and kept in the drum for 4 and 8 days, respectively.

Sap displacement treatment

For sap displacement treatment, freshly cut (89% MC) bamboo culm stakes prepared to size were immersed to 30 cm of the bottom part using kerosene held in an old oil- drum and leaving them standing in a receptacle containing kerosene for 4 days. Then, removed from the trough and air seasoned for a week.

Split stakes treatment

Stakes prepared to size, split into half and air-seasoned were pressure treated as stated above using Tanalith and borax- boric acid solutions separately and the 3rd batch were soaked in kerosene (Figure 5d). All the surfaces of the stakes were soaked. Then, after 8 days soaking, stakes were removed from the impregnation machine and dipping tanks, air seasoned for a week. Stakes treated with hot and cold dipping with crude table, soaking and sap-displacement with Kerosene were used for the non-ground contact tests.

Un-treated controls

Un-treated bamboo stakes receiving proper seasoning, moisture management and handling were used as a control. The controls provide information about the natural durability of the species.

Installation of stakes and damage evolution

Graveyard tests were simulating actual field and service conditions of bamboo culms. Pits for the installation of stakes were dug with 25 cm depth at a spacing of 25 cm between stakes and 50 cm between rows. Each plot per site and treatment was subdivided into 18 sections/parts. Test stakes were embedded randomly in the prepared pits by their bottom section up to 30 cm lengths. The position of all the stakes in each test plot was pegged facing to one direction following the position/direction of code plates and sketched to provide reference for the respective data collection work. All the graveyard sites were fenced with barbed wire, seasoned and preserved wood.

The off-ground stakes including soaking and sap displacement treatments were kept on shelves under shade, where there was no direct ground and moisture contact. Both graveyard and non-ground contact stakes were inspected and evaluated by mutual sounding/acoustic and visual method and data collection was carried out at three months interval i.e., 3rd, 6th, 9th and 12th months to check for their resistance/survival, and effectiveness of applied wood protection measures and application techniques.

The resistance and/or deterioration rate of each test stake against subterranean termites and fungal attack was determined by visual inspection/observation supported by sounding and indenting methods. In this study, earthen tunnels, termites mud tubes, and exit holes or galleries on the stakes were used to signify the presence and damage of subterranean termites. Fungal decay is characterized by color changes, softening, brashness, brittleness and the development of hype growth/decayed external appearance (assessed visually) and in later stages of decay forest products may shrunk and crack develop along and across the grain. A hollow seen and/or dull sound heard while jabbing the stakes with blunt end of the inspection knife and indenting with thumbnail were used to indicate fungal damage (Nicholas, 1985; Eaton and Hale, 1993; Shrivastava, 1997).

During the inspection, mostly after rainy season, each stake was carefully withdrawn from its pit, the presence and extent of attack by termites and/or fungi were assessed, evaluated and recorded following the method used by Gjovik and Gutzmer (1986) before its re-installation into the pit. Inspection of the graveyard was continued until the underground parts of at least 50% of the untreated and preservative treated stakes were completely degraded or fall down to the ground (Findlay, 1962; Gjovik and Gutzmer, 1986; IUFRO, 1972 cited in Willeitner and Liese, 1992).

Rate of biodeterioration was assessed based on a nominal scale of 1-5 where 1-sound, no decay and/or termite attack (100% resistance); 2-local, superficial/moderate attack (75% resistance); 3-slight attack, limited attack (50% resistance); 4-sever and deep attack (25% resistance); and 5-failure/complete attack (0% resistance) (Purslow, 1976; Gjovik and Gutzmer, 1986; Melaku Abegaz and Addis Tsehay, 1988; Willeitner and Liese, 1992; Eaton and Hale, 1993; Highley, 1995; Getachew Desalegn, et al. 2003).

Data analysis

The collected data were analyzed using SAS (2000), version 8.2 statistical software package. Multifactor ANOVA/combined analysis was used to determine damage by subterranean termite and fungi and effectivness of preservatives. Least significance difference (LSD) test was used to check the damage difference among biodeteriorating agents/mean separation among preservatives. Stakes mean damage values that became continuous values were used in the standard ANOVA. For convince of presenting results, scaled values after the data analysis were converted to percentage values.

Results and Discussion

Bamboo samples height, diameter and length of internodes

Mean height and diameter of bamboo sample culms of *Y. alpina* was 8.4 m and 5.20 cm and that of *O. abyssinica* was 6.1 m and 3.9 cm, respectively. Mean diameter of stakes for bottom position along the culms height was 4.5 cm, middle 4.1 cm and top sections 3.6 cm. Internodes length of *Y. alpina* and *O. abyssinica* was 42.2 cm and 33.7 cm, respectively. The internodes length of the Pawe site was relatively short. Mean number of nodes per 1 m length of both species stakes was 2.5.

Moisture content and density of bamboo species

The mean green (initial) and final (seasoned) MC of *Y. alpina*, respectively were 117.40% and 12.40% and that of *O. abyssinica* were 59.53% and 15.40%, respectively. Initial MC of bamboo samples collected from Hagere Selam, Injibara and Tikure Inchini were 103%, 115% and 134%, respectively and that of Asossa, Dedessa and Pawe bamboo culms was 56%, 54% and 69%, respectively. Final MC of Hagere Selam, Injibara and Tikure Inchini bamboo culms were 11%, 12% and 14%, respectively and that of Asossa, Dedessa and Pawe bamboo culms was 19%, 14% and 14%, respectively. Basic density (oven dry weight/green volume) of *Y. alpina* and *O. abyssinica* culm walls were 615 Kg/m^3 and 673 Kg/m^3, respectively. The density of Hagere Selam *Y. alpina* at 12% MC was 630 Kg/m^3 and according to Seyoum Kelemwork et al. (2008) three years old *Y. alpina* from Bore site, which is found near Hagere Selam had the same basic density of 630 Kg/m^3.

According to Seyoum Kelemwork (2012), the Asossa bamboo had basic density of 535 Kg/m^3 and Dedessa 615 Kg/m^3, the same as *Y. alpina* of this study while Pawe 658 Kg/m^3. The Pawe bamboo was comparable with this study in basic density and initial MC. The others differ in initial MC and basic density that could be due to site and age variations. The MC and density results of this study are in agreement with other reports which indicated that the initial MC of bamboo ranges 100 to 150% and seasoned density ranges 500 to 900 Kg/m^3 (Kumar and Dobriyal, 1988).

Treatability of bamboo culms with preservatives

Mean Tanalith preservative absorption per volume of treated *Y. alpina* and *O. abyssinica* culms at 3% concentration was 525.4 Kg/m^3 and 504.2 Kg/m^3, respectively. Absorption and retention (Kg/m^3) refers the amount of Tanalith salt absorbed and concentrate in bamboo culms, respecively. Tanalith absorption of *Y. alpina* stakes from Hagere Selam site was 575.3 Kg/m^3, Tikure Inchini 528.6 Kg/m^3 and Injibara 472.2 Kg/m^3. Stakes of *Y. alpina* from Hagere Selam site indicated relatively highest absorption (575.3 Kg/m^3) and Injibara the lowest (472.2 Kg/m^3). Absorption of *O. abyssinica* stakes from Asossa site was 659.4 Kg/m^3, Dedessa 733.4 Kg/m^3 and Pawe 119.7 Kg/m^3. Mean absorption of both species culms along height for bottom position was 214.2 Kg/m^3, middle 655.6 Kg/m^3 and top section stakes was 674.5 Kg/m^3. Top sections absorbed relatively highest and bottom the least (Getachew Desalegn *et al*., 2010).

Retention is more important than absorption, since what is effective in controlling biodeterioration attack on bamboo and wood is the retained amount. The average preservative retention of *Y. alpina* culms was 17.5 Kg/m^3. Stakes of *Y. alpina* from Hagere Selam site revealed relatively the highest retention (19.3 Kg/m^3) and Injibara the least (15.3 Kg/m^3). The average preservative retention capacity of *O. abyssinica* stakes was 17.1 Kg/m^3. Stakes of *O. abyssinica* from Dedessa site revealed the highest retention (24 Kg/m^3) and stakes from Pawe showed the least (5.5 Kg/m^3) preservative retention capacity. Mean retention of Tanalith at 3% concentration for both species along the culms height was 21.9 Kg/m^3 and the amount of preservative retained at the bottom, middle and top sections of bamboo was 8.1 Kg/m^3, 21.6 Kg/m^3 22.3 Kg/m^3, respectively. Top position stakes revealed the highest retention and bottom sections the least. The results showed that the retention of both bamboo were in the upper limit of the required retention level (4-20 Kg/m^3). This demonstrates that both bamboo species were permeable to preservative treatments.

Yunus-Uzzaman (1998) reported a maximum retention of CCA preservative 20.51 and 22.25 Kg/m^3 for air seasoned stakes of *Arundinaria flaconeri* and *Sinobambus tootsik*, respectively. Retention of 4-20 Kg/m^3 for water- borne preservatives such as Tanalith has been recommended to be adequate for various fields of applications (Willeitner and Liese, 1992). The retentions of both bamboo species and species by origin were also falling within the required retention limits. It has also been reported the bamboo specimens that has 11-19 Kg/m^3 retention when treated with CCA salt, is expected to have a service life span of 15-20 years both when used in the open and in contact with ground (Yunus-Uzzaman et al., 2001). Hence, the retentions of *Y. alpina* and *O.*

abyssinica obtained in this study were comparable with the results of Yunus-Uzzaman (1998) and Yunus-Uzzaman et al. (2001) and thus treated bamboo culms may have a long service life.

Accelerated decay laboratory test results

The fungus *Wolfipria cocos* inoculated on *Y. alpina* stakes resulted in production of mycelial growth. The inoculated stakes showed weight loss. Accordingly, the weight loss for untreated control, borax-boric acid treated stakes, Tanalith at 6% and Tanalith at 3% concentrations was 15.6%, 9.7%, 7.6% and 5.1%, respectively. Similarly, *O. abyssinica* stakes inoculated with the same *W. cocos* also lose weight. The weight loss of *O. abyssinica* control stakes was 6.8%, for borax-boric acid, it lost 7.8% of the weight, and the weight loss of samples treated with Tanalith at 6% and at 3% concentrations was 4.9% and 4.1%, respectively. The untreated (controls) of *Y. alpina*, had the highest percentage weight loss (15.6%) which is about double the weight loss of Tanalith preservative treated stakes. The stakes of *O. abyssinica* treated with borax-boric acid revealed the highest weight loss of 7.8%.

For both bamboo species, the application of different treatments as controlling measures for fungal attack showed significant difference ($P < 0.01$) in weight loss. Treating bamboo with Tanalith seems to be more effective in controlling fungal attack as compared to the borax treatment and the controls. According to Nellie et al. (2010a), in Kenya, *Y. alpina* stakes treated with 3% and 6% concentrations of Tanalith had significant difference ($P < 0.01$) in controlling fungal (*W. cocos*) attack and controls showed 16.6% weight loss, which is similar with the results from Ethiopia.

There was no significant difference ($P > 0.05$) in weight loss among the treatments under *O. abyssinica* of Ethiopia, implying that the chemical treatments and control did not contribute significantly in controlling the loss in weight of experimental units subjected to *W. cocos* fungus. This could be attributed to the natural durability of the species. In the case of introduced highland bamboo (*Dendrocalamus giganteaus*) of Kenya like the *O. abyssinica* of Ethiopia, treatments did not have significant effect in weight loss (Nellie et al., 2010a). Weight loss of 2-3% is statistically insignificant because of the inherent variability of this method. In this study, weight losses due to fungal attack were significant since most of the untreated and treated bamboo stakes revealed more than the weight loss limit stated above (2-3%).

Natural durability of bamboo and effectiveness of preservatives at graveyards

The evaluation made during the 3rd month revealed that majority of treated and untreated culm stakes of bamboo species at all sites were not significantly attacked by termites and fungi. During this period, none of the Tanalith treated stakes at 6% concentration and at all sites were damaged neither by termite nor by fungi (Table 2 and Figure 7). Effectiveness of preservative treatments against controlling termites and fungi significantly varied since the end of the 6th month's exposure. During the 6th month's exposure, at Pawe site, the highest termite damage (42.5% and 30%) was recorded for highland bamboo culms treated with borax-boric acid and the control, respectively (Getachew Desalegn *et al*. 2010). In Kenya, within 6th months of field exposure, the *Y. alpina* control stakes were degraded from 4.2% to 16% and that of *D. giganteaus* degraded from 12.5% to 33% (Nellie et al., 2010b). The evaluation in Ethiopia conducted at the 9th month revealed that effectiveness of borax-boric acid treatment at Pawe site was less than that of the untreated controls (Table 2).

Graveyard exposure of the untreated stakes at 1st year showed that the stakes originated from different localities in Ethiopia have different average soundness/resistance against subterranean termites. Accordingly, bamboo stakes originated from Hagere Selam and Injibara had 85%, Tikure Inchini 80%, Asossa 87.5%, Dedessa 82.5%, while Pawe had 92.5% soundness. In all the sites except Addis Ababa, deterioration rate of subterranean termites and fungi has increased significantly through time. Compared to the 6th month, the damage at 1st year increased from about twice to 24 times (Table 2).

Damage by subterranean termites on *Y. alpina* stakes from Hagere Selam and Injibara sites was the same value 15% and of Tikure Inchini 20%. In this case damage was not serious. During the same 1st year period, the highest termite damage on lowland bamboo occurred on control stakes (57.5%) and borax-boric acid treated stakes (52.5%) installed at Pawe. Highest fungal damage occurred on borax-boric acid treated stakes installed at Adami Tulu (40%) and Bako (30%) (Getachew Desalegn, et al., 2010). At Pawe site, fungal damage on controls exceeds the damage on stakes treated with borax-boric acid (Table 2).

The termite and fungal damage on bamboo revealed that culms cut near the ground surface or the underground parts were penetrated, excavated/hollowed, damaged and filled with moist soil by termites and in some cases decayed by fungi as well. When termites and fungi occur together they may become associated (symbiotic relationship) in a way so that they influence each other

(Wong and Cheok, 2001)). At Pawe and Bako sites, the above ground parts of bamboo culms were covered with soil sheathing up to 50 cm along the culms height during the rainy/moist periods and damage by termites and fungal infestation was observed.

Mean subterranean termites' damage on O. *abyssinica* stakes collected from Asossa site was 12.5%, Dedessa 17.5% and Pawe 7.5%. When comparing the two bamboo species, the natural durability of O. *abyssinica* was better than *Y. alpina*. The highest damage occurred on *Y. alpina* stakes obtained fromTikure Inchini (20%) and least (7.5%) on Pawe originated *O. abyssinica* culms. In general, the study bamboo species could be classified as non-durable

Subterranean termites' and fungal damage was also observed along the height of bamboo culms. The damage at the bottom, middle and top positions were 17.5%, 12.5% and 15%, respectively. No much biodeterioration difference along the culms position. The overall mean damage of fungi at all positions was 9.2% by termites. Mean termites' damage at each graveyard site, at all positions and for all preservatives in a descending order was Pawe 30%, Bako 20%, Adami Tulu site 10% and Addis Ababa nil (0%) damage. Damage of fungi at each graveyard site was 15% at Bako, 12.5% Adami Tulu, 5% Pawe and 2.5% at Addis Ababa site. Highest subterranean termites' damage (30%) occurred at Pawe and 15% fungal attack at Bako site.

At Addis Ababa research site, no termite damage recorded and the damage on controls due to fungal attack was very low (2.5%). About 78% of the untreated stakes at Bako site were damaged where, 22.5% of the damage was caused by termites and 17.5% by fungi. At Adami Tulu, about 78% of the stakes were attacked to 17.5% due to attack of termites and all of the stakes were attacked by fungi to 40% and the termites mound was extending from time to time and became very sticky around the stakes like cement concrete. Comparing termites' damage by graveyard, it was highest at Pawe and nil at Addis Ababa site. At Pawe site, the deterioration of the controls was 57.5%, used motor oil 27.5% and borax-boric acid 52.5% while fungal attack was estimated 0 to 12.5% (Getachew Desalegn, et al., 2010).

Table 2. Mean biodeterioration of bamboo stakes in terms of graveyard sites, preservatives and duration of exposure.

Graveyard station	Preservative	Mean termite and fungal deterioration (%) from 3rd month to 12th months field exposure							
		3rd month		6th month		9th month		12th month	
		Termite	Fungi	Termite	Fungi	Termite	Fungi	Termite	Fungi
Pawe	Control	0	0	30	0	40	0	57.5	5
Bako	Control	12.5	0	17.5	0	20	10	22.5	17.5
Adami Tulu	Control	2.5	2.5	12.5	20	17.5	27.5	17.5	40
Addis Ababa	Control	0	0	0	0	0	0	0	0
Pawe	Borax-boric acid	0	0	42.5	2.5	47.5	2.5	52.5	2.5
Bako	Borax-boric acid	2.5	0	20	0	27.5	5	37.5	30
Adami Tulu	Borax-boric acid	0	0	2.5	0	5	2.5	7.5	2.5
Addis Ababa	Borax-boric acid	0	0	0	0	0	0	0	5
Pawe	Used motor oil	2.5	0	22.5	10	27.5	7.5	27.5	12.5
Bako	Used motor oil	0	0	2.5	5	5	15	12.5	17.5
Adami Tulu	Used motor oil	0	0	2.5	0	5	7.5	15	15
Addis Ababa	Used motor oil	0	0	0	0	0	0	0	0
Pawe	Tanalith 3%	0	0	2.5	0	5	0	10	0
Bako	Tanalith 3%	0	0	5	2.5	15	7.5	15	7.5
Adami Tulu	Tanalith 3%	2.5	0	2.5	0	2.5	2.5	5	2.5
Addis Ababa	Tanalith 3%	0	0	0	0	0	0	0	0
Pawe	Tanalith 6%	0	0	2.5	2.5	2.5	0	2.5	0
Bako	Tanalith 6%	0	0	2.5	2.5	2.5	0	5	5
Adami Tulu	Tanalith 6%	0	0	2.5	0	2.5	2.5	2.5	2.5
Addis Ababa	Tanalith 6%	0	0	0	0	0	0	0	0

Note: 0% damage- indicates 100% resistance against termite and/or fungal attack while numbers refer damage extent in percentage.

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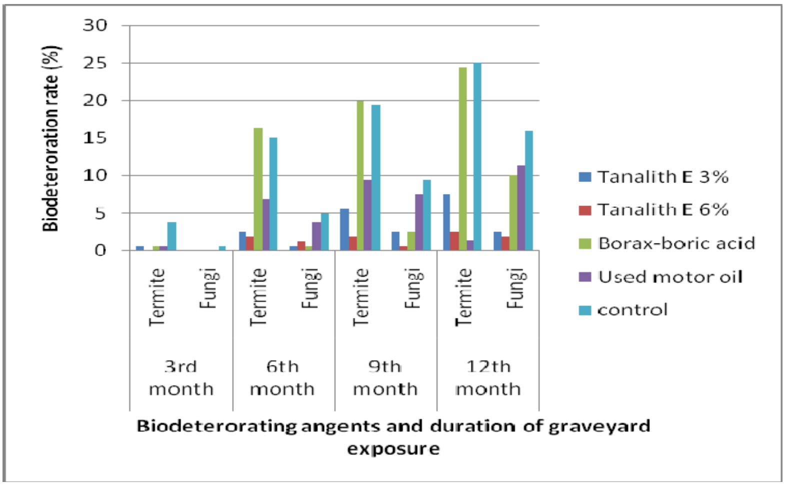

Figure 7. Mean deterioration of bamboo culms by subterranean termite and fungi against durations of exposure and preservatives.

The termites at Bako site were Microterms and *Pseudacanthoterms militarious* while at Zeway site about 5 km from Adami Tulu having the same agroecology as Adami Tulu site has been dominated by subterranean and mound building termite species, *Marcoterms bellicosus* (Zawde Berhane and Yusuf, 1974). The common/dominant mound forming termite species of Pawe are the genus *Macroterms* and *Odonototerms*, both belong to the family *Macrotermtinae* (Personal commutation to Pawe ARC researchers).

The damage of subterranean termites against preservative treated stakes was ranked in a descending order borax-boric acid and untreated controls (25%), used motor oil (12.5%), Tanalith at 3% concentration attacked to 7.5% and Tanalith at 6% revealed low damage rate of 2.5% (Table 2). The trend of termite attack at Pawe was observed from inner to outer parts and upwards, and at Bako from the bottom inner part to the top directions.

The graveyard evaluation from 3rd to 12th months revealed that there was significant difference ($P < 0.01$) in the mean biodeterioration damage of subterranean termites between species (*Y. alpina* and *O. abyssinica*), species by origin (Hagere Selam, Injibara, Tikure Inchini, Asossa, Dedessa and Pawe), positions along the culms height (bottom, middle and top), among preservatives

(Tanalith at 3% and 6% concentration, borax-boric acid, used motor oil and control), among preservative application methods (pressure, non-pressure and untreated controls) and graveyard sites (Pawe, Bako, Adami Tulu and Addis Ababa) and in the interactions between species by origin and preservatives; species by origin and graveyard sites; preservatives and graveyard sites. The same holds true for fungal damage too but in this case there was no significant difference (P >0.01) among species by origin and graveyard sites (Table 3).

Table 3. ANOVA values on deterioration rate of termite and fungi on bamboo culms at 1st year exposure period

Source^	DF	Type III SS	Sum of Mean Square	F Value	Pr > F
Location	3	69.72	23.24	62.45	<.0001*
	3	14.56	4.85	16.18	<.0001*
Preservative	4	48.71	12.18	32.72	<.0001*
	4	21.53	5.38	17.93	<.0001*
Position along height	2	1.84	0.92	2.47	0.0864
	2	0.001	0.003	0.01	0.9908
Bamboo spp. by origin	5	7.02	1.4	3.77	0.0025*
	5	1.38	0.28	0.92	0.4684
Preservative x location	12	48.81	4.07	10.93	<.0001*
	12	25.45	2.12	7.07	<.0001*
Position x location	6	1.36	0.23	0.61	0.7226
	6	0.93	0.15	0.52	0.7967
Bamboo spp. by origin x location	15	11.91	0.79	2.13	0.0088*
	15	5.12	0.34	1.14	0.3227
Position x preservative	8	3.82	0.48	1.29	0.2508
	8	2.19	0.27	0.91	0.5071
Bamboo species by origin x preservative	20	17.89	0.89	2.4	0.0009*
	20	13.94	0.70	2.32	0.0014*
Bamboo spp. by origin x Position	10	5.06	0.51	1.36	0.1988
	10	2.26	0.23	0.75	0.6737

^-the 1st value represented subterranean termites' damage while the 2nd value fungal damage, respectively.
**- significant at (P <0.01) level.*
x-indicates interaction between the two factors. $R^2T = 0.6795$; Cov = 38.80; $R^2F = 0.5151$; Cov = 40.66 where, Cov-coefficient of variation, F- fungi, R^2- coefficient of determination, spp- species, and T- termite.

Least significance difference (LSD)/mean separation test, to check the damage difference among biodeteriorating agents indicated that there was significant difference (P < 0.01) on subterranean termites and fungal mean damage among preservatives and graveyard sites. The LSD indicated that the overall mean damage due to subterranean termites and fungi for bamboo species, stakes from different origins, positions along the culms height, preservatives and graveyard sites was 15% and 10%, respectively. In case of termites, there was no significant difference between means of controls and borax-boric acid treatments (Table 4).

Table 4. Mean separation values (%) for preservatives against termite and fungal damage

Subterranean termite damage					Fungal damage				
t Grouping		Mean	N	Preservative	t Grouping		Mean	N	Preservative
	A	25	72	Control		A	17.5	72	Control
	A	25	72	Borax-boric acid	B	A	12.5	72	Used motor oil
	B	12.5	72	Used motor oil	B		10	72	Borax-boric acid
C	B	7.5	72	Tanalith 3%	C		2.5	72	Tanalith 3%
C		2.5	72	Tanalith 6%	C		2.5	72	Tanalith 6%

Means with the same letter are not significantly different.

For both bamboo species, species by origin, positions along the culms height and at all graveyard sites, mean deterioration of stakes up to 1st year, in terms of control, borax-boric acid, used motor oil, by subterranean termites was 25%, 25% and 12.5%, respectively and that of fungal attack was 17.5%, 12.5% and 10%, respectively (Table 4). Tanalith treated stakes at 3% concentration were deteriorated to 7.5% by termites and 2.5% by fungi. Tanalith treated stakes at 6% concentration were deteriorated by termites and fungi equally to 2.5%.

Application of different chemicals to control subterranean termites attack showed significant difference between used motor oil and Tanalith at 3% and 6% concentrations. The role of the chemical treatments to minimize the damage of fungi showed significant difference between borax-boric acid and Tanalith treatments (Table 4). In case of fungal attack, no significant differences were recorded between Tanalith treatments at 3% and 6% concentrations.

Comparison

In Ethiopia, there was no adequate record on natural durability of bamboo culms. The Palace ceilings of the King Minilik II at Entoto in Addis Ababa were constructed during 1889 from split bamboo culms that may be untreated has been still intact against biodeterorating agents (Personal communication and observation). Seasoned stems of *Y. alpina* used in construction and fencing are susceptible to infestation by the powder-post beetle *Dinoderus minutus*. However, in Democratic Republic of Congo, bamboo stems considered durable, houses and fences made from said to last for more than 20 years (Hall and Inada, 2008). Seasoned stems and fences made from the stems of *O. abyssinica* are susceptible to termite and borer attacks (Inada and Hall, 2008). No information on the effectiveness of preservatives on these Ethiopian bamboo species. In this study, preservative treatments such as Tanalith at 3% concentration and used motor oil treatments have increased service life of bamboo species culms by about 2-6 times compared to the controls and borax-boric acid treatments.

From the earlier timber preservation studies in Ethiopia, the underground parts of a few of the untreated timber stakes of *Acrcarpus fraxinifolius*, *Antarias toxicaria*, *Apodytes dimidiata*, *Trilepisium madagascariense*, *Milica excelsa*, *Croton macrostachyus*, *Ekbergia capensis*, *Fagaropsis angolensis* and *Polyscias fulva* at Zeway site were severely attacked and fell down to the ground line zone mostly by subterranean termites attack during the first three to six months field exposure periods (Getachew Desalegn et al., 2003). *Eucalyptus grandis*, *A. toxicaria*, *E. capensis and Podocarpus falactus* timber stake*s* at Mersa were degraded and fell down during the 2nd year period (Wubalem Tadesse and Getachew Desalegn, 2008). *A. fraxinifolius*, *A. toxicaria*, *A. dimidiata*, *C. macrostachyus*, *E. capensis*, *E. grandis*, *M. excelsa*, *Pinus patula*, *P. fulva*, *Pouteria adolfifriederici*, *Syzygium guineense* and *T. madagascariense* at Bako site were degraded and fell down by termite attack during the 1st year period (Getachew Desalegn et al., 2007).

All untreated control stakes of *C. macrostachyus* at Mersa, Bako and Pawe sites were degraded and fell down to the ground line during the 1st year (Wubalem Tadesse and Getachew Desalegn, 2008; Behailu Kebede *et al*., 2011) while *Cordia africana* during the 2nd year exposure period (Wubalem Tadesse and Getachew Desalegn, 2008). Untreated *Eucalyptus deglupta* timber at Meisso site was degraded and fell down at 1st year (Getachew Desalegn, 2010). Some of the control stakes of bamboo at Pawe, Bako and Adami Tulu sites fell down at 1st year. This revealed that untreated bamboo species at the same duration (up to 1st year) were comparable with the stated untreated timber species.

The non-ground contact/above ground test stakes of all untreated controls and preservative treated ones were intact against biodeteriorating agents namely termites, fungi and beetles. This was also true for the Kenyan part tests too (Nellie et al., 2010b). Both the graveyard and lab tests indicated that there was high damage when there were no preservatives applied indicating low durability of bamboo and importance of protection measures.

Uses of bamboo

At present bamboo in Ethiopia has good demand due to increasing use in industry, housing and other constructions. However, expansion of agricultural land, open grazing, settlements, fire and investments in other sectors, bamboo's

mass flowering and biodeteriorating agents as stated earlier are among the major driving factors against bamboo groves, products and services. Bamboos conservation, regeneration, products preservation and value added utilization has become a serious concern where large-scale and sustained production can contribute to secure its growth, sustenance and rational utilization in Ethiopia.
Bamboo resource has plenty of socio-economic and environmental products and services. Major product uses and service categories of bamboo in Ethiopia and elsewhere based on personal observations made during bamboo forests assessment and sample collection as well as literature review (Woldemichael, 1980; LUSO CONSULT, 1997; Kassahun Embaye, 2000; Ensermu Kelbessa et al., 2000; Melaku Abegaz et al., 2005; Wang, 2005-5006; Seyoum Kelemwork, 2006; Sisay Feleke et al., 2006; Seyoum Klemework, et al., 2008; Anonymous, 2010; Seyoum Kelemwork, 2011; Seyoum Kelemwork, 2012) are presented below:

- **Household utensils:** Baskets, water container, hats, woven mats, cups, local pipes, weaving shuttles and other tools, walking-sticks, agricultural tools, grain storages, sporting goods, musical instruments, toys, tool handles, stool, brooms, tooth picks, match stick, chopsticks, incense-stick, fruit trays, lamp shades, fishing poles, cricket boxes;
- **Furniture and handicrafts**: Chairs, tables, sofas, shelves, handicraft;
- **Construction**: House, hut, thatching and roofing, bridge, trusses, rafters, purlins, floor tiling, roof lattices, beams, pillars, ceilings, walls, windows, doors, partitions, fence, pole, scaffoldings, sleepers, beehives, mats, masts, re-enforcement of concrete instead of still rod, construction of nursery bed;
- **Industrial/structural applications:** Plywood, panel, laminated floor boards, pulp and paper, high quality panel products (medium density fiber board-MDF, strand boards-OSB, ply boards, bamboo curtain);
- **Food:** Emerging young culms/shoots of bamboo species are edible, succulent and notorious containing of fiber, calcium, iron, vitamin C, B and A, protein, carbohydrates, phosphorus, glucose and potassium (Sisay Nune, 2001). Bamboo shoots contain fatty acid content of about 1.1-1.4%. Highland bamboo contains high nitrogen content (5.4%) and high protein. Lowland bamboo has low nitrogen content (3.1%). The mean ash content for Tikure Inchini, Injibara and Masha sites was about 16%. The mineral elements include K, Ca, Mg, Mn, Cu, Zn and Fe (Sisay Feleke et al., 2006). The shoots of bamboo are considered very important nutrition for the Jeblawi people in the Asossa Zone of the Benshangul-Gumuz Regional State of Ethiopia;
- **Feed:** leaves and fine braches as animal fodder;
- **Beverages and juice:** Bamboo juice, beer and wine from bamboo leaf extractives; and

- **Biomass-based energy source:** Fuel, charcoal and briquettes.

All these products and structures including young edible shoots need proper handling, processing and applying protection maeasurs specific to each product and structure. Thus, most of these potential uses need through consideration of seasoning and preservative measures against biodeteriorating agents besides large scale development and management to promote sustainable and rational utilization of the bamboo resources in Ethiopia, Kenya and elsewhere.

- **Medicinal values:** Extractives from various parts of the plant have been used for hair and skin ointment, medicine for asthma, eyes, treating infections and potions for lovers and rivals (Yuming and Jiru, 1998; Rao and Rao, 1998);
- Source of cash income for many people; and
- **Live services of bamboo as a living plant** includes ornamental horticulture, environmental protection including soil conservation, ecological and agroforestry benefits and services (LUSO CONSULT, 1997; Kassahun Embaye, 2000; Ensermu Kelbessa et al., 2000; Gielis, 2002).

Conclusions and Recommendations

Bamboo has been used for different purposes (construction, furniture, fencing, source of cash income, environmental protection, etc) in Ethiopia without adequate knowledge of its durability, with no proper seasoning and no application of protection measures and without proper processing and not much value additions. Significant differences were revealed in biodeteriorating agents resistance among preservatives, graveyard sites, bamboo species and species by origin, exposure periods, between biodeteriorating agents and in the interactions between preservatives and graveyard sites, species by origin and preservatives. Performance of untreated stakes and effectiveness of preservatives against subterranean termites and fungal attack were varied. Results revealed that natural durability of the study bamboo species was low. Tanalith and used motor oil treatments were more effective against termites and fungi in ground and moisture contact applications and accelerated decay (fungi) lab tests compared with those of the borax-boric acid treatments and the controls.

Damage of subterranean termites was higher than fungi for both species, species by origin, all preservatives applied and at all graveyards sites of this study. Compared to the third month exposure period, the deterioration during the 6th, 9th and 12th months was significantly increased. The Addis Ababa site was less hazardous since underground parts of all the untreated stakes were 100% intact while the Pawe site was more hazardous since 100% of the controls and borax-boric acid treated stakes were touched and severely degraded by termites to 57.5% and 52.5%, respectively. All bamboo culm stakes exposed to the above ground dwelling termites, fungi and beetles were intact.

From the socio-economic and environmental importance, and bamboo's low durability point of view, proper seasoning and protection measures (non-chemical and chemical) against the various biodeteriorating and other agents has to be considered as inevitable measures to increase the durability of bamboo in service, widen application, guarantee structures and products long lasting and sustainable utilization of the versatile resource in Ethiopia.

The overall results are promising, indicating the paramount importance of bamboo culms preservation measures including proper seasoning to increase service life of bamboo and bamboo-based products and structures and to promote maximum utilization of the bamboo resources as construction and furniture material in Ethiopia. In this study, preservative treatments such as Tanalith at 3% concentration and used motor oil treatments have increased service life of bamboo species culms by about 2-6 times compared to the controls. Proper seasoning and adequate preservation of bamboo with the right protection measure including harvesting at proper age and season, handling and processing will lead to increase its quality (performance), value addition and service life, promote its sustainable development and rational utilization in Ethiopia that will reduce pressure on bamboo itself and endangered timber producing species and forests. The results will have practical application not only to the study areas (Pawe, Bako, Addis Ababa and Adami Tulu) but also in areas with similar bamboo species and agroecological zones. Results can be applied since there are different locally available protections measures with low price, small investment and some of the techniques of preservation in this case dipping and soaking can easily be applied with little technical knowledge.
Recommended protection measures to control/minimize damage of biodeteriorating agents and increase service life of bamboo culm based structures and products: (i) felling of mature bamboo culms during the low sugar season (dry period), in order to lower the starch/sugar content, (ii) harvested culms shall be properly handled and seasoned as soon as possible to the desired moisture content level using kiln or air. Air seasoning shall be done by placing bamboo

culms in a well-ventilated yard, under shade to avoid direct wind or sun as a quick seasoning may cause splitting, (iii) applying proper preservatives and application techniques for long time service ($\geq$ 10 years) using pressure and effective non-pressure (hot-and-cold dipping) methods, (iv) bamboo culms and products should not be used in hazardous areas for moisture and soil contact construction, other long-term and aesthetic applications without applying appropriate and adequate preservation measures, (v) use more environmental friendly and competent chrome and arsenic free commercial preservatives such as Tanalith E or Celcure AC type preservatives and the cheapest locally available spent motor oil of vehicles.

Damage of biodeteriorating agents in Ethiopia results in frequent replacement of structures/ constructions and bamboo based products. This has led to frequent harvesting/cutting of bamboo that would in turn lead to deforestation, erosion and environmental degradation. Therefore, the service life of bamboo from both socio-economic and environmental point of view has to be increased to sustain the present bamboo and timber stocks and future sustainable development and rational utilization in the country.

Further research involving different non-chemical/traditional and commercial preservatives at different sites and prolonged time are recommended to fill the information and technological gaps on durability, preservation measures, application techniques and rational utilization of bamboo resource in the different agroecological zones of Ethiopia where biodegradation and bamboo have economic relevance.

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Durability of *Cordia alliodora* Timber and Effectiveness of Preservatives in Protecting Timber against Termites and Fungal Attacks

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Introduction

The major sources of material for construction, forest industries, and wood-based energy sectors in Ethiopia are the natural forests while plantations including *Eucalyptus* species contribute about 10% (PTA, 1990; Alemu Gezhagne et al., 2004; Thomas and Million, 2003 cited in Abebe Haile et., 2009; Abebe Haile et., 2009). About half of the timber supplied (47590 m^3) to carpentry workshops of Addis Ababa originated from natural forests where 30% is originated from the protected forest species (Adugna, 2004 cited in Abebe Haile et., 2009).

Long-term durability and service life of wooden structures and wood-based products and structures/ services can be significantly increased by proper wood preservative treatments. Treatments can open the opportunity to new and wide application of timber species, which are susceptible for biodeterioration and refractory to treatments (NORDIC, 1981; Willeitner and Liese, 1992).

The damage on crops, rage lands and wooden constructions caused by termites in Ethiopia, was estimated at 20 to 50% which in some cases, has led to complete crop and construction losses that forced farmers to grow lower yielding but less susceptible crop varieties and/or forced to abandon their land, ruin their houses and move to less affected areas. *Macrotermitinae*, posed the greatest threat to wooden houses in the country, which led at least to partial rebuilding in 3-5 years (Wood, 1986; Cowie *et al*., 1990; Abdurahman, 1991; Ofgaa Djirata et al., 2007). In the different parts of the country, destruction of wood and bamboo-based constructions and products with soil and moisture contact applications occurred by subterranean termites and fungal mutual attack (Getachew Desalegn et al., 2003; Getachew Desalegn et al., 2007; Wubalem Tadesse and Getachew Desalegn, 2008) where the damages not to be considered as only caused by the attack of termites. According to Adane Bitew (2002) wood decaying basidiomycete species of 142 were recorded on *Pouteria* *adolfi-friederici*, *Juniperus procera* and *Podocarpus falcatus* R. B. ex Mirb. fallen logs from Menagesha, Munessa-Shashemene and Teppi forests of Ethiopia.

There have been only a few wood preservation studies made in the country, for the evaluation and identification of biodeteriorating agents, termite, and fungal damages, natural durability of timbers and performance of preservatives applied on a few timber species, agroecoligies and majority for short periods (< five years). Therefore, protecting wood/timber and bamboo products and structures from biodegrading organisms (insects and fungi) by treating with the appropriate preservatives and application techniques is imperative (Willeitner and Liese, 1992; Shrivastava, 1997).

The need to protect wood is to increase its service life, where the species is economically important, natural non-durable and susceptible to biodegrading agents. Wood protection can be effectively materialized if only the different characteristics of the species are known, appropriate preservatives with the required concentration and efficient techniques are applied. The challenge is thus, to investigate and select treatable and naturally durable furniture, construction and other utility timber species and effective preservatives against biodeteriorating agents, and find substitutes for the endangered timber species such as *Juniperus procera, Cordia afrcana, Popdocarpus falcatus*, and *Pouteria adolfi-friederici*, which the first four proclaimed not to be harvested from both federal and regional forests of the country (TGE, 1994) and the last one proclaimed only by Oromya Regional State (Forest Proclamation of Oromya, 2003).

Materials and Methods

Study site

The field test was conducted at graveyard stations near Meisso and Zeway urban areas. Meisso is located at about 26 km before reaching the Assebe Teferi town, Eastern Hararge, which is about 321 Km from Addis Ababa. The station is geographically located at 09°14′ North and 40°45′ East. It is found in the hot to-warm arid-lowland plains major agroecological zone and hot to-warm arid plains sub-agroecological zone (Anonymous, 2000). It has an altitude of 1400 m. Meisso area has mean annual rainfall of 717 mm, a bimodal rainfall where April and August receive the maximum rainfall and October to February is the dry spell (Alelign Kefyalewet al., 1996). It has mean annual minimum and maximum temperatures of 14.1°C and 33°C, respectively.

The 2nd study site was near Zeway town, 163 Km away south of Addis Ababa. The station is located in the lower core rift valley of Ethiopia at 07°56′ North and 38°43′ East. It is found in the Hot to Warm Sub-Humid Lowland major Agro-Ecological Zone, and Hot to Warm Sub-Humid Gorges Sub-Agro-Ecological Zone (Anonymous, 2000). It has an altitude of 1725 m, total annual rainfall of 642 mm, and the mean annual minimum and maximum temperatures of 12.4°C and 26.2°C, respectively. The station situated west of the town and established in 1987. Zeway site was dominated by subterranean and mound building termite species, *Marcoterms bellicosus* (Zawde Berhane and Yusuf, 1974). Both sites were located in areas where indicators of occurrence of termites are common and the damages on wood and wood based structures/ products serious. The sites were thus selected taking into account mainly biodeterioration hazardous in the area and density of the population with high demand of wood products for furniture, other utilities, construction and out-door service purposes.

Test materials

Lumber stakes preparation for laboratory and field tests

For preparing the wood stakes green logs were crosscut into 2.5 m logs and converted to tangential boards at the mobile circular sawmill by using flat sawing method. Tangential, radial, and longitudinal surfaces were conspicuous. All the laboratory and field stakes were made free from damages and visible defects.

The basic density of each stake was determined after conducting oven seasoning of samples to about 15% moisture content (hereafter MC) (IUFRO, 1972). Mean density of the species was determined from the ten stakes with a dimension of 2 x 2 x 3 cm in the tangential, radial and longitudinal directions, respectively (ISO/DIS 4469, 1975). This was done to make the stakes of the timber species used in the different treatments had comparable densities and MC.

For the laboratory preservative treatability (absorption and retention) as well as field studies (natural durability and effectiveness of preservatives) at two sites, a total of 80 stakes, i.e, ten per test were prepared from the timber species having dimensions of 2 x 5 x 50 cm (NWPC, 1971).

Preservative treatability of stakes

For the pressure treatment of all laboratory and field stakes, the commercial water-borne preservative, CCA fixing salt (type Celcure/Boliden K33) was used. The CCA was composed of 34% arsenate pentoxide (As_2O_5), 26.6% chromium trioxide (CrO_3) and 14.8% copper oxide (CuO) active ingredients, and the rest 24.6% was water and other ingredients (Richardson, 1978; Nicholas, 1983). The acute oral (ingestion) and acute dermal (skin) LD50s' (rat) of CCA were 300 and 800 mg/kg, respectively (Laporte, 1996).

Preservative treatments were applied on stakes marked with identification codes, after sawing and crosscutting wood to the final dimensions and seasoning to about 15% MC. Stakes for chemical permeability and chemical effectiveness tests were immersed into the Rentokil laboratory size Impregnation Machine (1985 Sweden brand), filled with a solution containing 24.5 Kg of CCA mixed with 820 liter of water in a 1:33 ratio of solute to solvent at 3% concentration.

The 10 pressure treatment/impregnation procedures (Willeitner and Liese, 1992; FAO, 1994) of CCA used in the study at ambient temperature were: (i) stacking the standard and seasoned (15% MC) timber stakes in the bogie and loading into the impregnation vessel and closing the door firmly; (ii) setting initial vacuum at 0.06 N/mm^2 for 30 minutes to avoid/reduce air from the wood so as to provide maximum space for the preservative; (iii) filling impregnation cylinder with preservative; (iv) increasing pressure to maximum; (v) adjusting treatment pressure to 1.0 N/mm^2 and maintaining for 1 hour to induce preservative into wood; (vi) releasing pressure; (vii) draining the preservative from the impregnation cylinder; (viii) setting final vacuum at 0.06 N/mm^2 for 30 minutes to drain surplus preservative from the treated stakes and get clean surface; (ix) releasing vacuum; and (x) withdrawing treated stakes from the machine and seasoning them at least for two weeks to about 15% MC so that the solvent is evaporated and preservative is fixed into the wood.

Treatability of stakes with preservatives was determined by weighing the stakes before and after treatment and by using the following adapted formulas (FAO, 1994; Willeitner and Liese, 1992; Getachew Desalegn et al., 2003; Getachew Desalegn et al., 2007; Getachew Desalegn, 2010): (i) Preservative Solution Absorption (Kg/m^3) = (A - B) / V, where A = saturated weight of stakes after treatment (Kg) and B = air - dried weight of stakes at about 12% MC, before pressure treatment (Kg); v = Volume of stakes before impregnation

(m^3); (ii) Retention (Kg/m^3) = [Weight of CCA/volume of stake] x concentration (%) = Absorption (Kg/m^3) x Concentration (%).

Control stakes for testing the natural durability of the species were not treated with preservative chemicals but receiving prophylactic treatments (proper handling during storage, transportation, processing, and seasoning to about 15% MC) to avoid discoloration and deterioration before field installation. The natural durability of timber species and performance of preservatives were expressed from durable to very perishable based on the modified and adapted grades (Purslow, 1976; Melaku Abegaz and Addis Tsehay, 1988; Eaton and Hale, 1993).

Stakes installation at graveyards and evaluation against bideterioration

Tests on the natural durability of stakes, performance of preservatives and application methods were conducted simultaneously in the field. At graveyard investigation the contributing effects of wood, preservative, weather, termite fauna and fungus flora were all interacting, as they would occur on treated wood (Nicholas, 1985) in commercial and untreated wood uses.

The holes (hereafter pits) used for the installation of stakes were dug 25 cm deep and had spacing of 25 cm between stakes and 50 cm between rows. For both natural durability and chemical effectiveness tests, the stakes were embedded randomly in the prepared installation pits with half their lengths (25 cm) in the ground and the rest half was remaining above the ground with identification tags fixed 5 cm from the top end. The trial station was demarcated with an area of about 20 x 20 m^2 and double fenced with barbed wire and live thorny plant species to make the site non-encroached to animals.

Evaluation of graveyard stakes deterioration

To determine the resistance and/or deterioration rate of each test stake against subterranean termites and fungal attack, visual inspection/observation supported by sounding and indenting methods were used. In this study, earthen tunnels, termites mud tubes and exit holes or galleries on the stakes were used to signify the presence and damage of subterranean termites. Fungal decay is characterized by color changes, softening, brashness, brittleness and the development of hype growth/decayed external appearance (assessed visually) and in later stages of decay stakes shrank and crack develop along and across the grain. A hollow and/or dull sound while jabbing stakes with blunt end of the inspection knife and indenting with thumbnail were used to indicate fungal damage. The methods of evaluation were adapted from Nicholas (1985) and Eaton and Hale (1993).

The main data collected at the field were resistance of untreated stakes and performance of preservatives over the study period. The inspection and evaluation of performance of untreated and treated stakes with preservatives was carried out at three, 6 and 12 months after installation of the stakes and every year thereafter (IUFRO, 1972 cited in Willeitner and Liese, 1992; Zawde Berhane and Yusuuf, 1974; Purslow, 1976). During the inspection, mostly after rain and by the same experts each stake was carefully removed from its pit, the presence, and extent of attack by termites and/or fungi were assessed, evaluated and damage rate recorded following the method used by Gjovik and Gutzmer (1986) and Highley (1995) before its reinstallation into the pit. Inspection of the graveyard was continued until the underground parts of 50% of the untreated and treated stakes were completely degraded and/or fell down to the ground (Findlay, 1962; IUFRO, 1972 cited in Willeitner and Liese, 1992; Gjovik and Gutzmer, 1986).

Grades from one to five (1-5) were used to determine biodeterioration of stakes: 1= sound, no decay and/or termite attack (100% resistance); 2= local, superficial/moderate (75% resistance); 3= slight, limited (50% resistance); 4= sever and deep (25% resistance); and 5= failure/complete attack (0% resistance) (Purslow, 1976; Gjovik and Gutzmer, 1986; Melaku Abegaz and Addis Tsehay, 1988; Willeitner and Liese, 1992; Eaton and Hale, 1993; Highley,1995; Getachew Desalegn, et al. 2003).

Design of experiments and data analysis

The design for the laboratory treatability experiment was completely randomized design (CRD) and in the field experiment split-plot in CRD with equal replication of 10 stakes per study species and preservatives was used. The data collected were subjected to one-way analysis of variance (ANOVA) to determine preservative treatability of each timber species, and multifactor ANOVA to determine performance of preservatives against subterranean termites and fungi. Mean of the 10 stakes, which becomes continuous variable, was used in the standard ANOVA (SAS Institute, 2000).

Results and Discussion

Treatability of stakes with CCA preservative

There was significant difference ($P < 0.01$) in timber stakes preservative absorption and retention. The results indicated that the absorption (uptake) and retention of *C. alliodora* stakes pressure treated with CCA preservative was about 574 kg/m^3 and 17 kg/m^3, respectively. Absorption and retention of stakes cold dipped with CCA was about 133 kg/m^3 and 4 kg/m^3, respectively while used motor oil treated stakes with hot and cold dipping method was 52 kg/m^3 and 2 Kg/m^3, respectively.

Resistance of used motor oil treatment

At Zeway up to third year inspection, used motor oil treated stakes of *C. allodora* were not attacked by termites and to 5% by fungi. Majority of used motor oil treated stakes at Meisso were attacked to 65% by termites and 20% by fungi (Table 1). This indicated that at Zeway, the resistance of *C. allodora* stakes treated with used motor oil against termites and fungi was better than that of Meisso. The high attack of termites and fungi at Meisso may be attributed to the favorable climate to them, although treatability of the Messio stakes with CCA was much better than that of stakes treated with motor oil and installed at Zeway site. This also revealed that the termites of Meisso were more aggressive than Zeway site. Treatments with used motor oil were less effective than CCA but effective when compared with other traditional control measures such as edible oil residue, slat and plastic bandage (Getachew Desalegn et al., 2003; Getachew Desalegn et al., 2007; Wubalem Tadesse and Getachew Desalegn, 2008; Getachew Desalegn and Alemu Gezaghne, 2010; Getachew Desalegn and Wubalem Tadesse, 2010; Getachew Desalegn, 2010).

Natural durability of *C. alliodora* timber and effectiveness of CCA treatments

The multi-factor ANOVA for both termites and fungal attack on the timber species indicated significant differences ($P <0.01$) between CCA treatments and the control, preservative application techniques (CCA pressure treated, cold dipped with CCA, and used motor oil hot and cold dipped treatments), between sites of Zeway and Meisso, and among length of field exposure periods (1/4th-3rd year). There was significant difference in the attack of termites for the interactions between preservatives and study sites (Table 2).

The mean results up to the last inspection period (3rd year) have been presented in Table 2. The rate of deterioration in Table 2 indicated that *C. alliodora* at Zeway site was 22.5% deteriorated by termite attack while at

Meisso station while the rate of deterioration for controls was 92.5% approaching felling complete damage status.

The results indicated that there was no significant difference between stakes CCA treated by pressure and dipping methods, 100% intact/resistance against termites and/or fungi while used motor oil treated stakes and untreated ones have been deteriorated by both termite and fungi to various extents (Table 2 and Figure 2). Compared to vehicles used motor oil treated stakes, untreated controls have been more attacked by both termites and fungi. At Meisso site, the CCA treatment with pressure and hot and cold dipping methods at Meisso site had increased service life by more than 10 times while used motor oil treatment to five times, and at Zeway both CCA and used motor oil treatments increased sevice life to about 1.3 times. The Meisso site and deteriorating agents there seem more hazardous than Zeway site.

The resistance of stakes treated with CCA and used motor oil against biodeterioration in the ground and during moisture contact application was significantly prolonged compared with those of the controls (Table 2). Performance of untreated stakes and effectiveness of preservatives against subterranean termites and fungal attack were varied. For both untreated and preservative treated stakes subterranean termites were the overriding agents, indicating more significant damage than fungi.

According to Wong and Cheok (2001) when termites and fungi occur together they may become associated (symbiotic relationship) in a way so that they influence each other. The trend of termite attack at Meisso was observed from inner to outer parts and upwards to the top directions.

Table 1. *C. allodora* untreated and treated stakes mean resistance results (%) against termites and fungi deterioration at each period of inspection and evaluation

Site	Treatments	Duration (1/4th year-3rd year)									
		1/4th year		½ year		1st year		2nd year		3rd year	
		T	F	T	T	T	T	T	T	T	F
Meisso	Control	60	90	32.5	65	20	65	12.5	65	7.5	60
	CCAP	100	100	100	100	100	100	100	100	100	100
	CCAD	100	100	100	100	100	100	100	100	100	100
	UMO	92.5	100	100	92.5	92.5	100	55	90	35	80
Zeway	Control	95	97.5	95	95	92.5	95	90	90	77.5	80
	CCAP	100	100	100	100	100	100	100	100	100	100
	CCAD	100	100	100	100	100	100	100	100	97.5	100
	UMO	100	97.5	100	97.5	100	97.5	100	97.5	100	95

T-subterranean termites, F- fungi; CCAP- Copper Chromium Arsenate pressure treated; CCAD- Cold dipping with CCA preservative and UMO-Used motor oil with hot and cold dipping method; Control-untreated.

Table 2. ANOVA values on deterioration of termite and fungi on *C. alliodora* stakes

Source	Biodeteriorating agents	DF	Type III SS	Sum of Mean Square	F Value	Pr > F
Location	T	1	**6.56**	**6.56**	**35.65**	**<.0001***
	F	**1**	**1.19**	**1.19**	**7.74**	**0.0166***
Preservative	T	3	**14.81**	**4.94**	**26.82**	**<.0001***
	F	**3**	**6.43**	**2.14**	**13.92**	**0.0003***
Time	T	**4**	**2.67**	**0.67**	**3.63**	**0.0368**
	F	**4**	**0.74**	**0.18**	**1.20**	**0.3612**
Preservative*location	T	3	**8.13**	**2.71**	**14.72**	**0.0003***
	F	**3**	**2.81**	**0.94**	**6.10**	**0.0092***
Time*location	T	4	**1.67**	**0.42**	**2.27**	**0.1219**
	F	**4**	**0.47**	**0.12**	**0.77**	**0.5655**
Preservative*time	T	**12**	**2.91**	**0.24**	**1.32**	**0.3205**
	F	**12**	**1.85**	**0.15**	**1.00**	**0.4971**

**- significant at 0.01 lvele.*

R2T -Square 0.9412; Cov.T- 28.51; Termite Mean-1.51; R2F -Square-0.8797 Cov.F - 30.47; Fungi Mean- 1.29where, Cov- coefficient of variation, F- fungi, R2- coefficient of determination, spp- species, and T- termite.

Conclusions and Recommendations

The results indicated that *C. alliodora* lumber CCA treated with pressure method and dipped samples were 100% intact/resistance against termite and/or fungi while used motor oil treated stakes and untreated ones have been deteriorated by both termite and fungi to a different extent. Compared to vehicles used motor oil treated stakes, untreated controls have been more attacked by both termite and fungi at both sites. The Meisso station and deteriorating agents there seems more hazardous than the Zeway site.

The results will have practical application not only at Meisso and Zeway areas but also in areas with similar timber species, agroecological zones and biodeteriorating agents. This could be beneficial for the potential anticipated beneficiaries of the expected outputs: farmers, rural and urban households, furniture factories, forest industries, sawmills and joineries, end-users of forest products, construction enterprises/sectors, civil- engineers, vocational training colleges, investors, concessionaires, development agents, foresters, researchers, policy makers, public, NGO's, individuals and the nation at large.

Forest products protection including seasoning and preservation against the various biodeteriorating agents has to be considered in Ethiopia among the necessary measures to increase the durability of wood in service, which can open the opportunity of using less durable timbers and to contribute the ever-increasing demand over supply for timbers from the threatened forest resources of the country. *C. alliodora* should not be used at Messio and Zeway and similar hazardous areas for moisture and soil contact construction and furniture applications and other utilities without applying adequate preservation measures. CCA and used motor oil preservatives shall not be used without considering the service life intended for the purpose, place of use, biodegrading hazards, its cost and applying adequate loading of the preservative. One can use more environmental friendly and competent chrome and arsenic free commercial preservatives such as Tanalith E or Celcure AC type preservatives having adequate protection like CCA and the cheapest locally available spent motor oil of vehicles.

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Resistance of Timber Species and Traditional Preservatives against Biodeterioration

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Introduction

There are more than 300 indigenous and homegrown exotic timber tree species in Ethiopia that can supply round wood and lumber/saw log. The research on their timber properties (characteristics) including resistance against biodeteriorating agents of wood and protection measures, however, has not been yet reached to an adequate level. The increasing need for more farms and grazing lands, and demand for wood-based energy, construction, furniture and other industrial materials are among the major causes of forest destruction in the country. In addition, tremendous amount of wood is destroyed by wood deteriorating agents due to lack of information and awareness on timber characteristics, seasoning, naturally durable timbers, effective protection measures, and application techniques. Such technical gaps on wood characteristics and utilization methods are among the causes in Ethiopia that led huge waste, short service life of wood and wood-based products and structures, inappropriate utilization of timbers, frequent harvesting and destruction of forests and endangering of certain ‘valuable tree species’ such as *Juniperus procera*, *Cordia afrcana* Lam., *Popdocarpus falcatus.*

Different wood-damaging organisms such as wood staining (sap and blue stains) and wood decaying fungi (brown-, white- and soft rot), termites, beetles, bacteria and marine borers available in the country. Biodeterorating agents all affect the quality and causing severe deterioration of non- durable timbers applied in ground and moisture contact constructions; furniture and other applications of wood both in rural and urban areas (Nicholas, 1985). In tropical and sub-tropical countries including Ethiopia, termites are the most aggressive insect enemy of wood having considerable economic important deteriorating agents. Termites are among the few insects, capable of utilizing cellulose from wood as a source of food and energy (Willeitner and Liese, 1992).

Cognizant to this, it is imperative to protect wood/timber and bamboo products from biodegrading organisms (insects and fungi) by treating with the appropriate preservatives and application techniques (Willeitner and Liese, 1992; Shrivastava, 1997). There have been only a few wood preservation studies made in the country, for the evaluation and identification of biodeteriorating agents, termite and fungal damages, natural durability of timbers and bamboo, and performance of preservatives applied, on a few timber species, agroecoligies and majority for short periods (< five years) (Holmgren, 1963; Zawde Berhane and Yusuf, 1974; Melaku Abegaz and Addis Tsehay, 1988; WUARC, 1995; Tsegay Bekele, 1996; Adane Bitew, 2002). At Zeway research station, 32 timber species and three preservation measures including the untreated controls were studied for 13 years (Getachew Desalegn et al., 2003) and the 11 years research at Bako (Getachew Desalegn et al., 2007) are so far the longest preservation research in the country while research at Bahir Dar, Gonder, Mersa, Negele Borena, Pawe, Yayu, Adami Tulu, Meisso and this study were among the shortest ones (Wubalem Tadesse and Getachew Desalegn, 2008; Getachew Desalegn, 2010; Getachew Desalegn and Alemu Gezahgne, 2010; Getachew Desalegn et al., 2010; Getachew Desalegn and Wubalem Tadesse, 2010; Behailu Kebede et al., 2011; Getachew Desalegn *et al*., 2012).

Damage on crops and construction materials occurred by termites in Ethiopia has been estimated at 20-50% (Wood, 1986). The greatest threat to wooden houses has been considered as caused only by the subterranean termites, which leads to complete or partial rebuilding in 2-5 years in the country (Wood, 1986). Destruction and frequent- replacement/reconstruction of wood and bamboo culms-based constructions occurred under soil and moisture contact applications in the different parts of the country due to subterranean termites and/or fungal mutual attack.

Podocarpus falcatus, the indigenous tree species has been one of the most prominent structural/ construction, furniture and other wood-based products, invaluable industrial and aesthetic materials in Ethiopia. *P. falcatus* is one of the very few highly targeted species for lumber production, highly exploited, improperly utilized and critically endangered species while *Acacia decurrns* Willd., *Grevillea robusta* R. Br., *Eucalyptus globulus* Labill., *Eucalyptus camaldulensis* Dehnh., *Eucalyptus regnans* F. Muell. are introduced fast-growing tree species for promotion and sustainable utilization. *P. falcatus, E. globulus* and *E. camaldulensis* have been used without adequate knowledge of their natural durability and other properties including effective preservation measures. Most of these home-grown exotic tree species are lesser known by the tree growers, forest products processors and end users in the country.

Selection and application of naturally durable timbers and effective wood preservation measures will be among the potential solutions to the great forest products degradation and the ever-exceeding timber demand over supply problems facing Ethiopia. If only the different characteristics of the species are known and appropriate preservatives with efficient techniques are applied, service life of forest products (wood, bamboo and others) can be increased.

The focus of this research was testing effectiveness of traditional preservatives on potential timbers species in controlling biodeteriorating agents' damage since they are less costly and easily applicable. Therefore, the objectives of this study were to: (i) examine effectiveness of traditional wood preservation measures against subterranean termites and/or fungal attack, (ii) identify natural durability of the timber species namely *A. decurrns*, *G. robusta*, *E. globulus*, *E. camaldulensis*, *E. regnans and P. falcatus*, (iii) select effective traditional timber protection measures for these timbers.

Materials and Methods

Study sites

The study sites were located at two agroecological zones at three graveyard stations, one in Oromiya Region at Bako-Tibe (West Shewa) and two in Amhara Region at Mersa (North Wello) and Maksegnit (North Gondar). Damage by biodegrading agents' and density of the population with high wood demand for ground and moisture contact construction and out-door purposes helped to select the graveyard sites.

Bako-Tibe (hereafter Bako) station is located near Bako- Tibe town, 240 km away west of Addis Ababa. It is geographically located in the sub-tropical climate, Shewa plateau at 09°07′ and 37°05′ (Figure. 1). It is found in the tepid to cool sub-humid highland major agroecological zone and tepid to cool sub-humid mountains sub-agro ecological zone (Anonymous, 2000). It has an altitude of 1800 m a.s.l, total annual rainfall of about 1342 mm, and the mean annual minimum and maximum temperatures were 12.4°C and 27.4°C, respectively.

Mersa station is 5 Km from Mersa town, 500 km away from Addis Ababa. It is geographically located in the 11° 49′N and 39° 36′E (Figure. 1) and it is found in the tepid to cool moist mid-highland major agroecological zone and tepid to cool moist mountains and plateau sub-agro ecological zone (Anonymous, 2000). It has an altitude of 1960 m, total annual rainfall of about 1073 mm and the mean annual minimum and maximum temperatures were 10.1°C and 25.7°C, respectively.

Maksegnit station is about 40 km from Gonder town, 710 Km away from Addis Ababa. The station situated near by the Maksegnit town. It is geographically located in the 12°32′N and 37°26′E (Figure. 1) and like Mersa has the same major- and sub- agro ecological zones (Anonymous, 2000). It has an altitude of 2270 m, mean annual rainfall of about 1172 mm, and mean annual minimum and maximum temperatures were 12.8°C and 26.5°C, respectively. Soil type of Bako-Tibe has been clayloam, both Mersa and Maksegnit has clay soil.

Study timber species and protection measures

The commonly used indigenous timber species *Podocarpus falcatus* (Zigba) and the five homegrown exotic timbers namely *Acacia decurrns* (Yewuchi-Grhar), *Grevillea robusta* (Gravillea), *Eucalyptus globulus* (Nechi-Bahirzaf), *Eucalyptus camaldulensis* (Camaldulensis- Bahirzaf) and *Eucalyptus regnans* (Regnans-Bahirzaf) were selected for the study (Table 1). The terms in bracket of the scientific name of timbers stands for local names in Amharic language. In average the selected and harvested trees were having a height of ≥ 10 m and a breast height diameter (dbh) at 1.3 m above ground of ≥ 30 cm.

Table 1. Description of the study timber species including their family name, place of sample collection, mean height and diameter

Timber species	Family	Place of sample collection	Height (m)	dbh (cm)
Acacia decurrens Willd.	Fabaceae	Holleta	18	32
Eucalyptus camaldulensis Dehnh.	Myrtaceae	Gimbi and Munessa	35	48
Eucalyptus globulus Labill.	Myrtaceae	Addis Ababa	21	30
Eucalyptus regnans F. Muell.	Myrtaceae	Munessa		
Grevillea robusta Silk/Sliver Oak	Protaceae	Gambella/Godere		
Podocarpus falcatus (Thunb.) Mirb.	Podocarpaceae	Wondo Genet	22	49

Note: Nomenclature of timber species follows that of Friis (1992); Lamprecht (1989); Webb et al. (1994).

The applied four preservatives including the control were common table salt, sodium chloride (NaCl), used motor oil of vehicles, and edible-oil residue (*Brassica carinata*).

Timber stakes preparation and treatment with preservatives

The procedure of sample trees selection, sample preparation (here after stakes) and treatments were: (i) trees were felled, bucked and designated with identification marks along height of the tree using waterproof permanent ink, (ii) green logs transported to Forest Products Utilization Research laboratory and converted to tangential boards of 2.5 m length, width equal to log diameter and 3 cm thickness at the sawmill using through-through sawing method, (iii) sample boards were planed, ripped and standard test samples prepared (IUFRO, 1973 cited in Willeitner and Liese, 1992) having dimension of 2 x 5 x 50 cm containing sapwood and heartwood parts. Forty samples were prepared from each timber species, 10 for each treatment and 240 stakes per research station; (iv) stakes marked with identification codes were treated with hot-and-cold dipping tank non-pressure method using used motor oil and salt separately, besides the un-treated controls.

Test stakes were prepared and selected proportionally from each tree and log along height of the trees. Stakes were uniform, straight grained and the annual rings were as parallel as possible to the 5 cm side, and free from damages and visible defects that may affect uniformity of the material and preservative treatments. Prior to the treatment, aluminum stainless steel identification tags were prepared with printed botanical names and site codes and fixed to each sample at about 5 cm from the top. For the field studies (natural durability and effectiveness of preservatives), for all the three graveyard stations a total of 720 stakes i.e., ten per species having dimensions of 2 x 5 x 50 cm (NWPC, 1971) were used.

Stakes for natural durability and traditional preservative effectiveness tests were air –dried (seasoned) to average moisture content below 18% and density determined prior to the preservative treatments and finally all stakes of each species were treated separately using hot and cold -dipping application techniques. Basic density of each timber specie stakes were determined using oven seasoning of samples to about 15% moisture content (IUFRO, 1972 cited in Willeitner and Liese, 1992) having a dimension of 2 x 2 x 3 cm in the tangential, radial and longitudinal directions, respectively (ISO/DIS 4469, 1975) mean density of each species was determined. In the different treatments, stakes of each timber species had comparable densities and moisture content.

The 1st batch of the test stakes were submerged in a dipping barrel containing 20 Kg salt and 80 liter water solution in a ratio of 1:4 solute to solvent and the 2nd batch were dipped in a 100 Kg cold-used motor-oil per timber species and the 3rd batch stakes were submerged into a barrel containing edible- oil residue diluted with water. In this test, twenty five Kg of edible- oil residue was diluted with 75 liter water in a ratio of 1:3solute to solvent.

All the three preservative treatments on each species stakes were applied separately using the same hot-and-cold dipping open tank/thermal atmospheric pressure method. The solutions were gradually heated to 90°C, the stakes being dipped inside and maintained for four hours. After 24 hours cooling, the treated stakes were withdrawn from the barrel and air- seasoned for two weeks before field installation so as to allow fixation of the preservative and/or solvent evaporation.

The un-treated control stakes for testing natural durability of each species were not treated with traditional preservatives but were set for prophylactic treatments (such as proper handling during storage, seasoning (about 15% moisture content) and processing, etc.) to avoid deterioration and discoloration before field installation. The control stakes without any traditional preservative treatment were used to determine the natural durability of each species.

Field tests

The field/graveyard sites were well drained, fairly leveled and having uniform soil conditions per station, easily accessible and hazardous by wood degrading agents (subterranean termites and fungi). The applied activities during graveyard establishment and stakes installation were: (i) the trial stations selected were demarcated with an area of about 20x20 m^2, cleared and double fenced with CCA treated wooden posts, barbed wire and with live fences from thorny species, to make the sites un-encroachable, (ii) holes (here after, pits) for the installation of stakes were prepared with 25 cm depth at a spacing of 50 cm between rows and 25 cm between stakes, (iii) three test plots were selected at three stations for each species, where each plot was divided into 40 sections for the four treatments containing 10 timber stakes (five sapwood and five heartwood) per treatment, (iv) test stakes were installed randomly in the prepared installation pits half the length (25 cm) of its full size.

The position of the stakes where each stake located in each test plot was indicated on the lay-out/ sketch map of the experiments. All the stakes had their identification tags facing the same direction so that they were replaced easily in exactly the same position after each inspection/evaluation and back filled with soil.

Inspection and evaluation of field stakes

The data collection on resistance and/or deterioration rate of each test stake against subterranean termites and fungal attack was determined by visual inspection/observation supported by sounding and indenting methods. In this study, earthen tunnels, termites mud tubes, and exit holes or galleries on the stakes were used to signify the presence and damage of subterranean termites. Fungal decay is characterized by color changes, softening, brashness, brittleness and the development of hyphal growth/decayed external appearance (assessed visually) and in later stages of decay timber stakes may shrunk and cracks developed along and across the grain. A hollow and/or dull sound while jabbing stakes with blunt end of the inspection knife and indenting with thumbnail were also used to indicate fungal damage (Nicholas, 1985; Eaton and Hale, 1993; Shrivastava, 1997).

The main data collected were termites and fungal attack rates that led to determine resistance/ natural durability of untreated stakes and performance of preservative treated stakes over the study period. Performance of untreated and treated stakes was determined through inspection and evaluation at six and 12 months after installation of the stakes, and every year thereafter (IUFRO, 1972 cited in Willeitner and Liese, 1992; Zawde Berhane and Yusuuf, 1974; Purslow, 1975; Eaton and Hale, 1993; Getachew Desalegn et al., 2003). During the inspection, mostly after rainy season and by the same experts, each stake was carefully withdrawn from its pit, the presence and extent of attack by termites and/or fungi assessed, evaluated and recorded following the method used by Gjovik and Gutzmer (1986) and Highley, (1995) before its re-installation into the pit. Inspection of the graveyard was continued until the underground parts of at least 50% of the untreated and untreated stakes were completely degraded and/or fell down to the ground (Findlay, 1962; IUFRO, 1972 cited in Willeitner and Liese, 1992; Gjovik and Gutzmer, 1986).The nominal grades from one to five (1-5) were used in this study, to determine biodeterioration of stakes, where: 1= sound, no decay and/or termites attack (100% resistance); 2= local, superficial/ moderate (75% resistance); 3= slight, limited (50% resistance); 4= sever and deep (25% resistance); and 5= failure/complete attack (0% resistance) (Gjovik and Gutzmer, 1986; Highley, 1995; Getachew Desalegn et al., 2003).

Design of experiments and data analysis

The design of the field experiment was split-plot in complete randomized design (CRD). A factorial experiment with one main plot factor, i.e six timber species, and two sub-plot factors namely two parts (sapwood and heartwood) and four preservative treatments (common table salt, sodium chloride, used motor oil of vehicles, and edible-oil residue). The analyses focused on natural resistance of timbers and effectiveness of traditional preservative treatments and application techniques against subterranean termites and fungal attack.

Comparison was done within and between the tree species, the sapwood and heartwood parts and applied preservative treatments and among the test stations.

Multifactor ANOVA was used to determine performance of preservatives against the stated agents. Mean damage values of the 10 stakes, which became continuous variable, was used in the standard ANOVA (SAS Institute, 2000). Since species were not structured, Duncan's multiple range tests were employed to determine significantly different treatment means thereby helping to determine which timber species, preservatives and periods were superior or inferior in their resistance against subterranean termites and fungal attack.

Results and Discussion

The multi-factor ANOVA results on subterranean termites deterioration revealed that there was significant difference ($P < 0.01$) among locations (graveyards), duration/exposure periods, timber species, sapwood and heartwood parts, preservatives, and in the interactions between timber species and preservatives, timber species and locations, preservatives and locations. In the case of fungal attack, there was significant difference ($P < 0.01$) among locations, exposure time, timber species, and in the interactions between timber species and locations, timber species and exposure times. Thus, the type and extent of attack varies with timber species, preservatives, locations, exposure times and biodeteriorating agents (termites and/or fungi) (Table 2). The sapwood part of sample stakes of all the tree species were found to be more liable to biodeterioration as compared to samples obtained from heartwood parts of each of the studied tree species (Table 2).

For *A. decurrens* at Bako station, effectiveness of preservatives in descending order was used motor oil, control, edible oil residue and edible salt. At Maksegnit station, used motor oil was not much better than the others. Used motor oil treated stakes of *E. regnans* and *P. falcatus* were degraded and felled at 3rd year unlike others (Table 3).

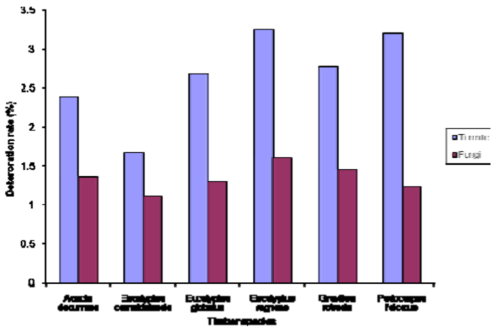
Untreated *E. camaldulensis* was superior at all stations, while *E. regnans* was inferior in its resistance against termites and fungal deterioration. At Mersa and Gonder stations, E. *camaldulensis* was the top in resistance. A. *decurrens* was the second while *E. regnans* was the least resistant species. At Mersa, there was no significant difference among natural durability of the timbers namely *Eucalyptus globulus*, *E. regnans*, *G. robusta* and *P. falcatus* and the four preservative treatments (Figure. 2ab).

Table 2. ANOVA values on deterioration rate of termite and fungi on timbers, preservatives, field sites and duration of exposure

Source^	DF	Type III SS	Sum of Mean Square	F Value	Pr > F
Location	2	183.99	91.99	371.57	<.0001*
	2	27	13.50	119.83	<.0001*
Preservative	3	26.95	8.98	36.29	<.0001*
	3	1.990	0.66	5.88	0.0006*
Sapwood and heartwood part	1	8.70	8.70	35.15	<.0001*
	1	0.63	0.63	5.56	0.0187*
Time	3	206.45	68.82	277.96	<.0001*
	3	102.39	34.13	302.98	<.0001*
Timber species	5	162.68	32.54	131.41	<.0001*
	5	13.84	2.77	24.57	<.0001*
Preservative x location	6	17.39	2.90	11.71	<.0001*
	6	1.14	0.19	1.69	0.1208
Sapwood and heartwood part x location	2	1.47	0.74	2.97	0.0521
	2	0.94	0.47	4.15	0.0163
Time x location	6	23.78	3.96	16.01	<.0001*
	6	46.51	7.75	68.81	<.0001*
Timber species x location	10	30.29	3.03	12.24	<.0001*
	10	9.43	0.94	8.37	<.0001
Preservative* Sapwood and heartwood part	3	1.29	0.43	1.74	0.1586
	3	0.21	0.07	0.62	0.6045
preservative x time	9	2.15	0.24	0.97	0.4678
	9	2.53	0.28	2.50	0.0085*
Timber species x preservative	15	33.58	2.24	9.04	<.0001*
	15	2.47	0.16	1.46	0.1141

^-the 1st value represented subterranean termites' damage while the 2nd value fungal damage, respectively.
**- significant at (P <0.01) level.*
x-indicates interaction between the two factors. $R^2T = 0.8582$; *Cov* = 18.73; $R^2F = 0.8074$; *Cov* =25.10 *where, Cov- coefficient of variation, F- fungi,* R^2*- coefficient of determination, spp- timber species and T- termite.*

At Maksegnit station, used motor oil has been observed the least effective preservative for *E. regnans*, *E. globulus and G. robusta* stakes, unlike other sites. This entails further research on used motor oil at this area. Edible oil residue and salt were least effective for *P. falcatus*. At this station, majority of the stakes (control) and treated ones were not attacked by fungi.



2a.

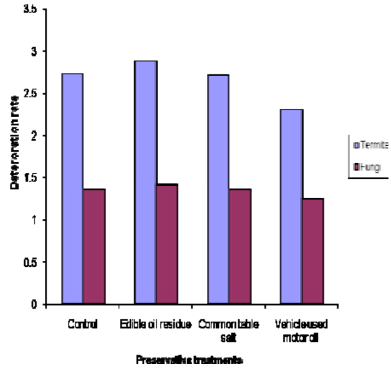


Figure 2. Deterioration of timber stakes (Figure. 2a) and preservatives (Figure. 2b) by termite and/or fungi expressed as means of least squares [Rates/Grades: 1= sound, no decay and/or termite attack (100% resistance); 2= 75%, 3= 50%; 3.5= 37.5].

At Bako, *E. camaldulensis* was the top resistant against termites and fungal attack. *E. globulus* was the second while *E. regnans* was the least resistant species. Control stakes of *E. regnans* and majority of preservative treated ones were highly attacked and felled at Maksegnit station by termites compared with the other species and stations (Table 2). In general, termites' deterioration was high at Mersa while fungi at Bako station (Table 3 and Figure. 3a). At Bako site, the salt treated stakes above ground parts were highly attacked may be by rats since stakes were tasty.

The biodeterioration rate of untreated and treated timber species during the three years exposure in the field varied. In general, more untreated stakes were deteriorated to 0% level resistance while treated ones resisted to 100% (Table 3 and Figurs 2 and 3). Besides, the tepid to cool moist mid-highland major agroecological zone and tepid to cool moist mountains and plateau sub-agro ecological of Mersa and Maksegnit was more hazardous than the tepid to cool sub-humid highland major agroecological zone and tepid to cool sub- humid mountains sub-agro ecological zone of Bako.

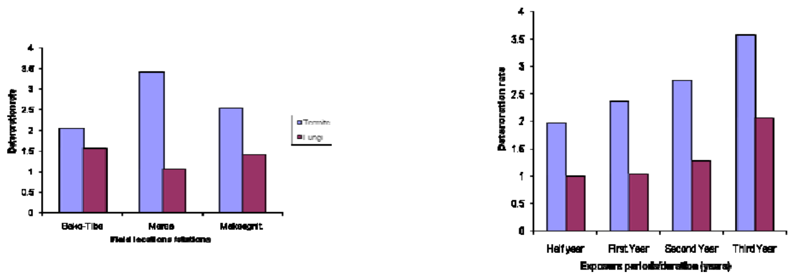
Table 3. Mean biodeterioration resistance of timbers and effectiveness of traditional preservation measures (%) at the research stations up to the last inspection period (3rd year)

Timber species	Preservative Treatments	Resistance of timbers and preservative effectiveness (%) at different study sites					
		Bako (West-Shewa)		Mersa (North Wello)		Maksengit (North Gonder)	
		Termites	Fungi	Termites	Fungi	Termites	Fungi
Acacia decurrens	C	45 (1)	47.5	32.5	75	25	82.5
	E	37.5 (2)	42.5	32.5	70	32.5	85
	S	32.5 (3)	40	50	65	20	100
	U	57.5 (1)	57.5	50	80	22.5	100
Eucalyptus camaldulensis	C	75 (1)	90	72.5	90	85	100
	E	60 (1)	67.5	60	82.5	45	100
	S	62.5 (1)	82.5	55	85	52.5	100
	U	90	100	75	97.5	57.5	100
E. globulus	C	57.5 (1)	55	45	62.5	5	100
	E	57.5	60	45 (2)	67.5	17.5	100
	S	40 (1)	65	47.5	62.5	12.5	100
	U	72.5	62.5	45 (2)	67.5	0 (All)	100
E. regnans	C	45 (4)	7.5	12.5	70	0 (All)	100
	E	32.5 (4)	47.5	10	45	0 (All)	100
	S	27.5 (5)	35	25 (3)	12.5	10	97.5
	U	47.5 (5)	25	30	57.5	0 (All)	100
Grevillea robusta	C	55	50	27.5 (1)	55	15	97.5
	E	30 (2)	42.5	27.5 (1)	30	25	100
	S	27.5 (3)	52.5	27.5 (2)	52.5	22.5	100
	U	82.5	72.5	22.5 (3)	65	2.5	97.5
Podocarpus falcatus	C	12.5 (2)	70	25	97.5	25	90
	E	7.5 (4)	60	12.5	70	0 (All)	92.5
	S	17.5 (3)	47.5	25	92.5	0 (All)	100
	U	97.5 (3)	87.5	40	85	32.5	97.5

**-The numbers in the brackets show the number of stakes completely damaged and failed to the ground line zone within three years.*

Abbreviations: C- Control (untreated); E- Edible oil residue; S- Table salt and U- Used motor oil with hot and cold-dipping treatments.

The control stakes of *E. camaldulensis* at Bako station, up to 3rd year were attacked to 25% and 10% by termites and fungi, respectively. Timber stakes of *E. camaldulensis*, from similar preservation test carried out earlier at Bako were attacked only to 30% and 10% up to year four by termites and fungi, respectively (Getachew Desalegn *et al.,* 2007). *E. camaldulensis* stakes at Zeway station up to year five,were attacked only to 45% by termites (Getachew Desalegn et al., 2003). *E. camaldulensis* stakes of this test treated with used motor oil at Bako station and up to 3rd year were attacked to 10% by termites. On the other hand, at the same station, *E. camaldulensis* stakes treated with used motor oil, up to year five were attacked to about 33% by termites (Getachew Desalegn *et al*., 2007). Effectiveness of traditional preservatives in a descending order at all locations was used motor oil, salt, untreated control and edible oil residue, respectively. Used motor oil compared with the other preservatives was the best effective preservative while edible oil residue and table salt were the least effective preservatives where edible oil residue was even less than the control at all stations (Table 2, Figure 3).



3a. 3b.

Figure 3. Deterioration of timber stakes against locations (Figure. 3a) and durations of exposures (Figure. 3b) by termite and/or fungi expressed as means of least squares [Rates/Grades: 1= sound, no decay and/or termite attack (100% resistance); 2= 75%, 3= 50%; 3.5= 37.5].

The control stakes of *E. globulus* of this study, at Bako station and up to 3rd year were attacked to 43% and 45% by termites and fungi, respectively. *E. globulus* control stakes from other similar studies were felled at year four at Bako, and at Zeway resisted termites attack for more than 10 years (Getachew Desalegn *et al*., 2003; Getachew Desalegn *et al*., 2007). *E. globulus* stakes treated with used motor oil of this test up to 3rd year were attacked to 23% and 37% by termites and fungi, respectively (Table 3).

At Bako, the control stakes of *P. falcatus* up to 3rd year were attacked to 87% and 30% by termites and fungi, respectively and from former tests at Bako, *P. falcatus* stakes were felled at year three by termites, while at Zeway resisted termites attack up to 12 years (Getachew Desalegn *et al.,* 2003; Getachew Desalegn *et al*., 2007). *P. falcatus* stakes treated with used motor oil up to 3rd year were attacked to 3% and 18% by termites and fungi, respectively (Table

23). This indicated that in the case of *P. falcatus* the site at Bako was more favorable to biodeterorating agents than Zeway.

Duncan's Multiple Range analysis (mean separation test) indicated that there was significant difference ($P < 0.01$) between subterranean termites and fungal mean damage on timber species, preservatives, and exposure periods (Table 4). The overall mean damage due to subterranean termites and fungi for all the timber species, preservatives and graveyard sites was scaled to 2.8 (45%) and 1.4 (10%), respectively.

Table 4. Mean separation values (%) for preservatives against termite and fungal damage.

Subterranean termite damage					Fungal damage				
t Grouping		Mean	N	Preservative	t Grouping		Mean	N	Preservative
	A	52.5	144	Edible oil residue		A	90	144	Edible oil residue
B	A	57.5	144	Control	B	A	90	144	Salt
	B	57.5	144	Salt	B		90	144	Control
	C	67.5	144	Used motor oil	C		95	144	Used motor oil

Means with the same letter are not significantly different.

Duncan's Multiple Range analysis also revealed that biodeterioration attack rates among timber species, preservatives and exposure periods were different from each other. The superiority of timber species in resisting subterranean termites attack in a descending order was *A. decurrens, E. camaldulensis*, *E. globulus*, *E. regnans*, *G. robusta* and *P. falcatus*, while against fungal attack the superiority of timber species in a descending order was *E. camaldulensis*, *P. falcatus, E. globulus*, *A. decurrens*, *G. robusta* and *E. regnans.* According to Duncan's Multiple Range analysis, the superiority of preservatives against subterranean termites and fungal attack in a descending order was used motor oil, salt, control and edible oil residue (Table 4). The controls were better than the edible oil residue treatments. This was also true for Mersa and Negele-Borena sites too (Wubalem Tadesse and Getachew Desalegn, 2008).

During the three years exposure in the field, variation in biodeterioration rate was also shown between the untreated and treated timber species. In general, the untreated stakes were completely deteriorated to failure (0% level resistance) while the treated stakes showed 100% resistance (Figure. 2 and 3). Damage due to biodeteriorating agents varied with exposure time span. As the duration of treated and un-treated stakes increased in the field, damage from biodeterioration also increased for the majority of the timber species stakes (Figure. 3b). Year three was the highest biodeterioration occurred while sixth month was the least. The damage increased by two and half times in the 3rd year when compared to the sixth month inspection.

When the timber species, preservatives, locations, and field exposure time are considered, the damage caused by subterranean termites was highly greater than that caused by fungi for all timber species, preservatives, and durations and at all stations. When termites and fungi occur together, they may become associated (symbiotic relationship) in a way so that they influence each other (Wong and Cheok, 2001).

The trend of termites and fungal attack was observed from inner to outer parts and upwards to the top directions. Stakes and the corresponding treatments and field locations in Figure. 4a from left to right refers *E. regnans*$_{EB}$, *Podo*$_{SB}$, *Podo*$_{EB}$, *A. decurrens*$_{SG}$, *E. camaldulensis*$_{UG}$, *G. robusta*$_{SG}$, *A. decurrens*$_{CM}$, *G. robusta*$_{CG}$ and *G. robusta*$_{UM}$ while in Figure.4b from left to right refers *E. regnans*$_{EB}$, *Podo*$_{SB}$, *Podo*$_{EB}$, *A. decurrens*$_{SG}$, *E. camaldulensis*$_{UG}$, *G. robusta*$_{SG}$, *A. decurrens*$_{CM}$ and *G. robusta*$_{CG}$. The first subscript letters next to the scientific name indicates preservative treatments: C-control, E- edible oil, S-salt, U-used motor oil. The 2nd subscript letters next to the scientific name indicates graveyard localities: B-Bako, G-Goner and M-Mersa stations.

Most of the six timber species stakes and of the preservatives tested at Bako, Mersa, and Maksegnit indicated that the service life could be significantly increased when the right timber species and appropriate protection measures are employed. The six timber species treated stakes compared to the controls have increased durability from about 1.3 to 8 times. To control damage by subterranean termites and fungi used motor oil treatment could be used as measure for non-durable timber species such as *E. regnans*, *G. robusta* and *P. falcatus* when intended for construction purposes (poles, piles, posts, pillars, sleepers, etc.) that involve moisture and soil contact applications.

Conclusions and Recommendations

Untreated timber stakes were deteriorated to failure (0% level resistance) damage while treated ones resisted to 100% (no damage). Effectiveness of the traditional preservatives tested in a descending order was used motor oil, salt, control and edible oil residue. Used motor oil was the best effective preservative while edible oil residue and table salt were the least effective preservatives, where edible oil residue was even less than the control at all stations. For all the study timber species, preservatives and at all stations, termites were the prevailing wood deteriorating agents. The results of this study will have good implication to Bako, Mersa and Maksegnit stations and to other areas with similar agroecological zones, biodeteriorating agents and timber species.

The following recommendations are forwarded: (i) very susceptible and non-durable timber species such as *E. regnans* should not be used without adequate preservative measures at Bako, Mersa and Maksegnit and similar hazardous areas for moisture and soil contact construction and furniture applications, (ii) further research work on long duration base (≥ 10 years) is recommended on service life of these six timbers and effectiveness of preservatives and application methods in different agroecological zones of Ethiopia including Bako (West Shewa), Mersa (North Wello) and Maksegnit (North Gonder) areas. Therefore, for ground and moisture contact construction and furniture applications where appropriate, effective preservatives such as used motor oil (It cannot be used for furniture items) and naturally durable as well as potential timber species such as *E. camaldulensis* and *A. decurrens* have to be used for the service life not exceeding 10 years and these timbers have to acquire priority focus for sustainable development, appropriate management and rational utilization in Ethiopia.

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Physical Characteristics And Potential Uses of *Acacia Ployacantha* Timber

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Introduction

In Ethiopia, the supply of wood comes from different forest and vegetation types that include natural forests, woodlands, bush lands, industrial and peri-urban plantations, community woodlots, catchments and protected forests. With the rising standard of living of the people as well as the rapidly increasing number of construction and furniture industries, the need for timber, panel and fiber products is increasing tremendously. The total wood and woody biomass required for industries, construction and fuel was estimated to about 47.4 million m^3 in 1992. With the current growth rate of the population the same demand will reach to about 94.8 million m^3 by the year 2014 (EFAP, 1994) where demand will exceed the supply by about 900%.

To satisfy the ever-increasing demands of the consumers, large quantities of timber, panel and fiber products are being imported from different countries with hard currency. Currently, forests are being cleared in excess of the replacement due the increased demand for wood for household energy and construction materials. In addition, tree species utilized by the different industries for various wood products are limited in number. This selection of tree species paired with the low recovery rate of the sawmills, further processing as well as inappropriate utilization due to lack of information and/or technologies on different wood properties (characteristics) and utilization methods has resulted in the degradation of the existing forests both in quality as well as quantity. Conversely, there are more than 300 tree species whose benefits are not yet fully realized. However, this was not made possible due to lack of efficient technologies for alternate use of less utilized forest resources.

Among the major factors that would seriously affect the quality, appearance and performance of wood and wood-based products has been inappropriate drying (seasoning) and density. The different characteristics of each timber species, its suitability for different purposes and more than 90% of all the challenges associated with wood and its utilization involves moisture amount, its influence, and fluctuation with time, environmental conditions and management (Hodaley, 1989; Simpson, 1991; Denig et al., 2000; FPL, 2010). Moisture content (MC) affects weight, density, strength, durability, workability, and overall performance of wood, including its serviceability.

According to Denig et al. (2000), 75% of the manufacturing problems in furniture plants are probably related to in correct moisture content of lumber. Some important advantages of properly seasoned lumber compared to wet/green lumber include: (i) having average and spread MC within individual pieces and for entire load, (ii) good appearance, (iii) being more than twice strong and about twice stiffer, (iv) has 40-50% less weight, (v) shrinks very little or none at all while in service, (vii) no or minimal seasoning defects such as warp, checks, splits and casehardening, (viii) machining, gluing and finishing are much easier to accomplish and (ix) quick penetration of wood preservatives and other paints.

Thus, MC, density and mechanical properties, seasoning and shrinkage characteristics (tangential, radial, longitudinal and volumetric), seasoning rates and defects are among the major factors that determine the quality, utilization and service life of wood as round and sawn lumber (Hodaley, 1989; Simpson, 1991; FPL, 2010; Denig et al., 2000; Getachew Desalegn, 1989, 2006). Therefore, estimating density and managing moisture content in wood for the intended purposes and environment of applications will be an important consideration towards enhancing the different characteristics and rational utilization of timber species in Ethiopia where deficit of wood supply is very high (EFAP, 1994).

Proper timber seasoning as a science of uniform moisture removing from wet or 'green' wood by evaporation under more or less controlled conditions is a natural resource conservation-oriented and profitable process that will minimizing MC in wood and seasoning defects, enhance its properties, achieving the highest possible quality and makes the lumber more valuable for rational utilization to a great extent (Simpson, 1991; Denig et al., 2000).

Seasoning defects are unavoidable and occurred while seasoning each tree species lumber but the extent varies from species to species and with the method of seasoning applied. This is due to shrinkage and other wood characteristics, the main causes of quality degrade. Most seasoning defects that develop on wood products during seasoning can be categorized as fracture (rupture-surface and end checks) or distortion (collapse and honeycomb-internal cracks), warp (cup, bow, twist, and spring) and discoloration caused by an interaction of wood properties with processing factors. Defects that arise due to shrinkage resulted in warping while that arises due to uneven seasoning leads to rupture of the wood tissues such as checks, splits, honey-combing and case-hardening. Understanding them will provide a means to minimize defects (Simpson, 199; Denig et al., 2000; FPL, 2010).

Shrinkage and swelling of wood is the basic cause of many inevitable problems that occur in wood during seasoning to ≤ 25% MC and in service (Denig et al., 2000). As wood loses moisture (bound water) below the fibre saturation point (< 30 % MC), it shrinks (decreases in dimension), and as water enters the cell wall structure the wood swells (increases in dimension). Shrinkage and swelling characteristic is an exactly reversible process in small pieces of stress-free wood (Haygreen and Bowyer, 1996). Shrinkage of wood is the basic cause of many problems that occur in wood during seasoning to ≤ 25% MC and in service (Denig et al., 2000). The major shrinkage characteristics are warp (cup, bow, twist and crook/spring-side bend), distortion/split in- and-around knots, and other seasoning stresses (cracks and checks) (FPL, 2010; Denig et al., 2000). The major cause of warp is differential shrinkage caused by the differences in tangential, radial and longitudinal directions during the seasoning process (FPL, 2010; Denig et al., 2000; MTC, 2002). According to Denig et al., (2000), the only factor of importance that causes shrinkage and swelling are moisture loss, and gain, respectively.

The density values of the timber were determined, as prime indicators of wood quality, as a guide to seasoning behaviour, rate of seasoning and as an index of weight since it has strong influence on the different properties (seasoning rate and defects, shrinkage, physical and mechanical properties, etc.) and timber quality (ISO 3131, 1975; Denig et al., 2000; MTC, 2002).

A. polyacantha tree species is fast-growing indigenous hardwood and potential species for promotion and sustainable utilization in Ethiopia (Hedberg and Edwards, 1989; Demel Teketay et al.’ 2010). It is not yet known by the development sectors, manufactures, and end users in the country. It is worth to undertake integrated research on such economically lesser-known and fast-growing timber species and wood based products in order to maintain sustainable supply of alternative raw mistrials and increase value addition efficiency and select appropriate utilization of technologies for the construction, industry, and furniture manufacturing sectors.

Therefore, the general objectives of this study were to investigate properties (characteristics) (seasoning, appearance, and density) and potential uses of *A. ployacantha* sawn timber. Specific objectives of this study were to: (i) evaluate seasoning methods for the timber, (ii) determine seasoning characteristics and density of the species at different MC levels, (iii) study appearance, shrinkage characteristics, seasoning defects and biodeterioration attack during and after seasoning and, handling techniques for sawn wood and, (iv) assess potential uses of the timber.

Materials and Methods

Test materials

Botanic description: It is a tree up to 20 m high and 50 cm in diameter; crown broadly umbelliform to parasol or obtriangular. Bark, yellowish grey or yellowish brown, rough, scaly, with fine and horizontal annular rings, flaking off in thin papery patches, fissured and exposing knobby persistent prickles. Blaze about 1 cm thick; slash red or light red with white streaks outer, yellowish white inner, fibrous, soft. Weakly unpleasant odour. Exudation of a pale yellowish reddish, translucent gum, in a long run, not abundant. Young branchlets pubescent or puberulous. Prickles in pairs, 4-15 mm long. Leaves: pinnae 13-60 pairs; petiole with a conspicuous gland, 1.5-4 mm long; leaflets, 25-68 pairs, 2-6 x 0.4-0.9(-1.25) mm, usually only the midrib visible beneath. Flowers yellowish-white, sessile, in up to 13 cm long spikes. Calyx 1.5-2.25 mm long, puberulous or pubescent. Corolla 2-3 mm long. Pods straight, dehiscent, 6.5-18 x1·2.1 cm, brown, veined, glabrous or nearly so. Seeds subcircular, 7-9 x 6-8 mm; areole 3-4 x 2.5-3.5 mm. (Hedberg and Edwards, 1989; Thirakul, 1993; Azene Bekele-Tesemma, 2007; Anonymous, 2009; Anonymous, 2012a).

A. polyacantha is fast growing on good sites with pollarding and coppicing management (Hedberg and Edwards, 1989; Demel Teketay et al., 2010). In Gibe and Konta areas, it has been under- pressure for charcoal production and conversion to agricultural land.

Habitat and Geographic Distribution: It is a species that occurs in the sub-humid to humid African tropics and also in wooded grassland, deciduous woodlands and bush lands as well as riverine and ground water forest covering an altitudinal range of 500-1,600 m and mean annual rainfall of 300-1000 mm. It prefers sites with a high groundwater table, indicating eutrophic and fresh soils. It occasionally prospers on stony slopes and compact soils (Thirakul, 1993; anonymous, 2009). *A. polyacantha* occurs as native in Botswana, Eritrea, Ethiopia, Gambia, India, Kenya, Senegal, Sierra Leone, South Africa, Sri Lanka, Sudan, Swaziland, Uganda, Tanzania and Zambia (ANONYMOUS, 2009; Anonymous, 2012a). In Ethiopia, it occurs in Dry and Moist Kolla Agroclimatic Zones of Gamo Gofa, Gojam, Gonder, Ilubabor, Kefa, Shewa, Sidamo and Tigray Regions (Hedberg and Edwards, 1989; Bekele-Tesemma, 2007).

Propagation and germplasm management: *A. polycantha* is mainly seed propagated. To get good germination results, the seed coat should be nicked at the distal (cotyledon) end using a sharp tool like a scalpel, knife or nail clipper. On average, there are 15 000 seeds/kg. Storing with insecticides is recommended. No. of seeds per kg: 14,000-16,000. Seed can be stored if kept cool, dry and insect-free (Hedberg and Edwards, 1989). Seed storage behavior is orthodox. A purity of 98% can be achieved. Seed weight depends on provenance and the climatic conditions of the ripening year. Mature and properly dried seeds can be stored in airtight containers at room temperature for at least one year and at 10°C for several years. Large quantities of seeds should be treated by pouring boiling water on them in a vessel. Then, the seeds should be left for 24 hours in the water as it cools. Under ideal conditions, the seeds germinate within 10-21 days. The expected germination rate of mature, healthy and properly treated seed is 60-90% (Anonymous, 2009). Establishing possible using seedlings, wildings, direct sowing.

Flower: Like most acacias, flowering depends highly on the rains. The cream-white, sessile flowers are inserted in spikes up to 15 cm long. They are produced together with new leaves. After pollination by insects, straight fruits with distinctly narrow, thickened margin are developed within six months; fruits are tapered on both ends. When mature the pods turn greyish-brown. The seeding period can be observed approximately six months after flowering (Anonymous, 2009).

Harvesting of logs and sample preparation

Log sawing, sample preparation, lumber stacking, testing and determination of the different wood characteristics of *A. polyacantha* was based on the methods adapted from Tack, 1969; ISO 3130, 1975; ISO/DIS 4469, 1975; Desch, 1986; WUARC, 1989; Simpson, 1991; Reeb, 1997 Denig et al., 2000; MTC, 2002; FPL, 2010.

The timber used in the test of the different wood properties (hereafter referred to as characteristics) were obtained from Gibe and Konta sites, Southern

Nations, Nationalities and Peoples Region. Sample trees were harvested, 20 trees from of Gibe since it was having short height and low diameter, and from 10 trees of Konta site since it was having long height and diameter.

Sample trees were harvested from matured and morphologically defect-free and good quality trees. Sample trees from Gibe site were having a height of 8-13 m, clear bole length of 2.5-5 m and breast height diameter (DBH) of 14-20 cm and that of the Konta site a height of 17-31 m, clear bole length of 6-13 m and a breast height diameter (DBH) of 25-38 cm. Trees were felled and bucked into 2.5 m logs. Logs, while green (> 30% MC) were transported to Forest Products Utilization Research Laboratory (Addis Ababa).

Logs at the mobile circular sawmill by applying through-and-through type of sawing method were sawn to 3 cm thick tangential boards. Samples were prepared proportionally from each tree and log along height and marked with identification codes using waterproof permanent ink. For the following-up of the seasoning processes and determination of moisture content (MC), rate of seasoning and defects,16 defect- free sample boards per sample origin site, a total of 32 samples with dimensions of 100 cm in length, 3 cm thickness and width equal to log-diameter were prepared and used.

Green (hereafter, initial) MC of the timber species was determined from the samples, two small sections (1.2 cm length and 3 cm thickness and width equal to log diameter) cross-cut into 20 cm inwards from each sample board ends to eliminate the effects of end seasoning. Thirty two defect- free sample specimens at initial state with standard dimensions (length, width and height) of 2 x 2 x 3 cm were used for the determination of shrinkage characteristics and density at different MC.

Sawn lumber stacking and seasoning tests

Sawn boards were immediately transported to the air seasoning-yard and kiln-seasoning areas and stacked at 3 cm spacing between successive boards. Boards were stacked horizontally in vertical alignments separated by well-seasoned, squared, and standard stickers as stated below, and top loading was applied to counteract against warping (cup, bow, twist, and crook/spring). In air seasoning stacks, 50 Kgm^{-2}, 40 cm thick and two-meter long solid wood blocks were applied while in kiln seasoning heavy stones weighing about 50 Kgm^{-2} were loaded. The loads on the stacks were applied at a spacing of 0.5 m interval.

During lumber staking, standard stickers with a dimension of 2.5 x 2.5 x 180 cm and 2.5 x 2.5 x 20 cm (width, thickness and length, respectively), were prepared and placed at equal distance, 0.5 m interval across each layer of lumber, aligned on top of one another from the bottom of the stack to the top. This was done to facilitate uniform air circulation, distribute the weight of the lumber vertically from top to bottom and conduct uniform seasoning, minimize warp and to avoid stain and decay occurrence during the seasoning process. Long stickers were used to separate boards while the short strips placed up on the long stickers were used to easily access the sample boards of each stack, withdraw from the stack, measure the current weight, and replace into the stack.

The seasoning samples were distributed in each stack to represent the lumber in the sack and the seasoning process at different positions (top- bottom, left right and vice-versa). Weighing and replacing the samples into the stack was done repeatedly until the MC reached the desired amount about 12% MC. Where the heartwood and sapwood boards were clearly separated, the sapwood boards were placed at the sides, top, and bottom of the stacks since they have more MC than the heartwood. The heartwood boards were placed in the middle. *A. polyacantha* in this case has sapwood and wider heartwood. The ends of boards were made equal on both directions and the control sample boards were properly distributed and positioned in the pockets of the different layers of each stack.

Seasoning involves timely application of adequate temperature, relative humidity and air circulation as critical activity (FPL, 2010). Seasoning is the process of uniform moisture reduction from wood and increase quality/serviceability and required wood/forest products to be used in most products and services. Control of the seasoning process is, thus, the key to successful and efficient seasoning. Natural (air) and artificial (kiln) seasoning methods were used for testing and determination of seasoning characteristics of *A. polyacantha*. Initial weights and dimensions (length, width, and thickness) of all air and kiln seasoning sample boards were measured using sensitive electrical balance and calliper, respectively, immediately after planing and crosscutting. Small sections (3 cm thick and 1.2 cm length) cross-cut from seasoning sample boards (3 cm thick and 1 m length) for the determination of initial MC were weighed at four hours interval as soon as samples were withdrawn from the oven drier to minimize moisture absorption and desorption (Desch, 1986; Denig et al., 2000). Seasoning is usually accomplished by seasoning “from the outside in” and evaporating the moisture from the surface of the wood where the amount of moisture leaving the wood will be determined by the relative humidity of the atmosphere surrounding the wood (Reeb, 1997).

Boards for air seasoning were stacked under air seasoning yard on firm foundations having 45 cm clearance above the ground and a dimension of 4 x1.80 x 0.45 m. This was done to facilitate good air circulation and reduce the direct influence of fungi, temperature, wind, and relative humidity. Boards were stacked under shed without direct interference of moisture, rainfall, sunshine and aligned north-south direction where the ends were not facing the wind direction. In kiln seasoning method, after stacking boards out of the kiln on the transfer carriage (1.6 x 0.30 x 2.7 m) were placed inside the kiln-seasoning chamber.

Air seasoning

Air seasoning is an attractive method of seasoning from green to about 20% MC (Denig et al., 2000). The seasoning sample boards were re-weighed and re-placed into the stack at one-week interval. This was continued until the difference between two successive weights of each specimen became 0.1-0.2 g and the final weight was taken as the oven dry weight (ISO 3130, 1975; FPL, 2010). The process was continued until the average final MC of the stack reached about 12%, which is the equilibrium MC for in- and out- door purposes, and standard for comparison within and between timber species.

Seasoning of wood/forest products is required to be used in most products and services. Control of the seasoning process is thus the key to successful and efficient seasoning. Seasoning involves timely application of adequate temperature, relative humidity and air circulation as critical activity (FPL, 2010).

Kiln seasoning

Boards of air and kiln seasoning tests were underwent an initial air seasoning before stacking and commencing the regular air and kiln seasoning processes so as to reduce kiln/electric charges during kiln seasoning. The conventional type of kiln seasoning machine has been well insulated and having about 2.5 m^3 wood loading capacity room per kiln operation was used in this study. In this case timber remains stationary and the temperature and humidity of the circulated air were altered in a set sequence/a schedule which has been selected that may suit the material being seasoned.

The kiln-seasoning machine has controlled air circulation, temperature and humidity mechanisms where temperature and humidity can be adjusted using psychrometers (dry bulb and wet bulb thermometers) to get quality lumber after seasoning. It has been equipped with fans to force air circulation and air outlet, and operates at temperature ranges of 40ºC -70ºC. The seasoning schedule, a serious of temperature and relative humidity steps at different corresponding MC levels was selected based on the initial MC, density and botanical category of the species either hardwood or softwood timber. Kiln seasoning schedule Ethiopia Number 3 (hardwood schedule type) was applied.

Kiln samples in a similar way like air seasoning described before were weighed and dimensions measured. Uniform air circulation and seasoning, controlling the seasoning process and maintaining the quality of the seasoned wood was managed by taking measurements and changing the direction of the fan at eight hours interval, three times at 24 hours.

Moisture content and seasoning rate determination

The conventional oven- dry weight-method of MC determination (ISO 3130, 1975; Lavers, 1983; Haygreen and Bowyer, 1996; Reed, 1997; FPL, 2010; Denig et al., 2000; MTC, 2002) was applied. The general formula applied for MC (%) determination presented in equation 1.

$$MC\ (\%) = (IW\text{-}OD/OD)*100 = (IW/OD\text{-}1)*100 = (W/OD)*100 \qquad (1)$$

Where, IW= initial weight of wood with water (g), OD = oven dry weight of wood without water (g), W = weight of water alone (IW-OD) (g).

The air and kiln seasoning rates of the timber species were determined from the MC samples of each stack. Seasoning rate classification for air and kiln seasoning stacks was done based on the adapted standards from Longwood (1961) and Farmer (1987), respectively.

Determination of shrinkage and swelling characteristics

Samples for shrinkage characteristics (tangential, radial and longitudinal directions, and volumetric) determination of *A. polyacantha* lumber were seasoned in the oven - seasoning chamber/microwave to a constant dimension (until the difference between two successive weights of each specimen became 0.1-0.2 g) at a temperature of 105°C. Dimensions (Initial and current) and weight of all samples were measured similar to MC tests, but, in this case, measurements were carried out once per day. Then, the final weights and dimensions were taken as oven dry weights and dimensions, respectively.

Shrinkage characteristics and shrinkage rate of each specimen from green (61%) to 12% MC, and to oven dry (0%) MC, were determined using the different adapted formulas (ISO/DIS 4469, 1975; ISO/DIS 4858, 1975; Simpson, 1991; Haygreen and Bowyer, 1996; Reeb, 1997; Denig et al., 2000; MTC, 2002). The general and specific formulas for the shrinkage characteristics (%) presented in equations 2-6.

Shrinkage characteristics (%) = (Decrease in dimension (mm)/green (Initial) dimension (mm))*100... (2)

Tangential shrinkage (%) = [(T1-T2)/T1]*100= (1-T2/T1)*100...................................... (3)

Radial shrinkage (%) = [(R1-R2)/R1]*100 = (1-R2/R1)*100.. (4)

Longitudinal shrinkage (%) = [(L1-L2)/L1]*100 = (1-L2/L1)*100.................................... (5)

Volumetric shrinkage (%) = [((V1-V2)/V1]*100= (1-V2/V1)*100...................................... (6)

Where, T1, R1, L1, V1- green (initial) tangential, radial, longitudinal and volumetric dimensions in mm before oven seasoning progression commenced, respectively, and T2, R2, L2, V2- final (seasoned) tangential, radial, longitudinal and volumetric dimensions in mm after oven seasoning progression, respectively.

Mean swelling characteristics values of *A. polyacantha* timber on tangential, radial, longitudinal and volumetric were determined based on the adapted equation 7 (Haygreen and Bowyer, 1996; Anonymous, 2012b).

Swelling characteristics (%) = (Decrease in dimension (mm)/dry dimension (mm))*100........................ (7)

Seasoning defects

According to Simpson (1991), Denig et al.(2000) and FPL (2010), most defects or problems that develop on wood products during and after seasoning can be categorized as warp, rupture of wood tissue (fracture- surface and end checks and splits) or distortion (collapse-flattening or crushing of wood cells, honeycomb-internal cracks/splits occurs in wood rays), uneven MC and discoloration caused by an interaction of wood characteristics with processing factors, and they are the main causes of non-stain related seasoning defects. Wood shrinkage is mainly responsible for wood ruptures and distortion of shape while drying/seasoning temperature is the most important processing factor is responsible for defects in each category (Simpson,1991; Denig et al., 2000) stated above.

Density test

The density (g cm^{-3} or Kg m^{-3}) and/or specific gravity values of the species were determined from the shrinkage samples, procedures and measurements as stated earlier using mathematical formulas. Specific gravity (unit less) is the density of wood per density of water, numerically equal to density since an equal volume of water at 4 °C has a density of 1 g cm^{-3} or 1000 Kg m^{-3}

(Lavers, 1983; Haygreen and Bowyer, 1996; Denig et al., 2000; MTC, 2002). Density was determined at different MC and sample volume conditions (ISO 3131, 1975) using the following formula:

Basic density = (Sample oven dry weight/sample green volume)..... (8)

The dry density values were converted to standard 12% equilibrium MC (Table 1) by applying the following formula (ISO 3131, 1975) and classified based on the adapted standard classification (Framer, 1987).

Density at 12% MC ($\rho 12$) = Pw* [1-0.01*(1-K_O)*(W-12)]...... (9)

Where, Pw = density of wood at test, Ko= coefficient of volumetric shrinkage for a range in 1% MC and W = weight of water alone (initial weight minus oven dry weight of wood). For approximate calculations, the value of K_o= $0.85*10^{-3}$*Pw when density is expressed in Kg m^{-3} and K_o = 0.85*Pw when density is expressed in g cm^{-3}.

Density values (Kg/m^3) classifications adapted from Farmer (1987) and categorized as exceptionally light < 300, light 300-450, medium 450-650, heavy 650-800, very heavy 800-1000 and exceptionally heavy > 1000.

Results and Discusssion

Moisture content

The mean green (initial) and seasoned (final) MC of the *A. polyacantha* timber were about 61 and 16%, respectively. In air and kiln seasoning, the mean initial MC of sample boards of each stack were 60.8 and 61.1% (Table 1), respectively. The mean initial and seasoned MC of lumber from Gibe site were 42 and 12.1%, respectively. Similarly, the mean initial and seasoned MC of lumber from Konta site were 79.5 and 22.4%, respectively.

The results indicated that the mean final air seasoned MC for this species was 19.19% while the final kilns seasoned mean MC was 12.22% (Table 1 and Figure. 4). During dry period, it is possible to season lumber to less than 20% MC by air seasoning since lumber with < 20% maximum MC has no risk of developing stain, decay or mould (Denig et al., 2000) which could be used for outdoor and above ground construction purposes. Air seasoned lumber can have ≤ 25% MC with no lumber material having > 30% MC. In kiln seasoning it is possible to season to the desired amount even up to 0% MC, for instance for musical instruments. Kiln seasoned lumber can have an average specified MC of typically 6-8% or a MC suitable for certain use (Denig et al., 2000).

There was difference in the mean air and kiln seasoning green (initial) and final MC of sawn boards (Table 1).

Table 1. Seasoning and density characteristics of *A. ployacantha* timber

Origin of samples	Air seasoning stacks MC (%) and rate of seasoning (days)*			Kiln seasoning stacks MC (%) and rate of seasoning**			Density (Kg/m³)		
	Initial MC of air seasoning stacks	Final air Seasoning MC	No. of days in air seasoning	Initial MC of kiln seasoning stacks	Final kiln seasoning MC	No. of days in kiln seasoning	Green /Initial	Basic density	At 12% MC
Gibe	42	15.97	62	46	12.13	5	750	590	640
Konta	79.5	22.4	62	76.2	12.3	5	780	550	610
Mean	60.75	19.19	62	61.1	12.22	5	765	570	625

*-Air seasoning rates (days) have been adapted from Longwood (1961) and classified as very rapid < 77 days; rapid, 77-119; moderate, 126-182; slow, 183- 189; very slow > 189 days.

**- Kiln seasoning rates (days) have been adapted from Framer (1987) and classified as very rapid <10.5 days; rapid, up to 10.5; fairly rapid (moderate), 10.5-17.5; fairly slow, 17.5-30; slow, 30; very slow, over 30 days.

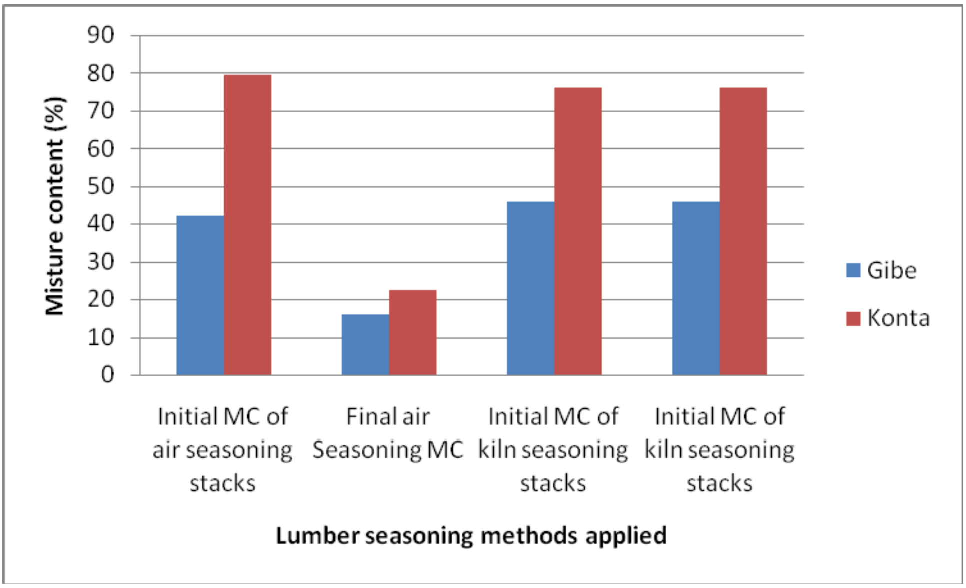

Figure 4. Green and seasoned MC (%) of *A. polyacantha* lumber from Gibe and Konta sites.

The mean initial MC of air and kiln seasoning stacks was different within species while the final kiln seasoned MC was similar for the lumber from Gibe and Konta sites (Table 1). The mean final MC of kiln-seasoned wood based on its purpose may vary from 0 to 25% (Denig et al., 2000).

Rate of seasoning

The rate of mean air and kiln seasoning of timber-sawn boards of 3 cm thickness to reach to about 12% MC were 62 and five days, respectively (Table 1). Depending on the species and size of timber, the time taken to reach 20-25% MC vary from 2 or 3 months to 1 to 2 years (MTC, 2002). With air seasoning, wood cannot season below its equilibrium MC and this will vary about 16-17% MC depending on the atmosphere conditions. Air seasoning alone is not sufficient for timber intended for most interior use 8-12% is required (MTC, 2002). Based on the adapted rate of seasoning categories (Longwood, 1961; Farmer, 1987), the timber of *A. polyacantha* can be classified as very rapid in both air and kiln seasoning methods. Species comparable with *A. polyacantha* in air seasoning rate with accuracy of ± 5%, and determined with the same method and laboratory, were *Acacia decurrens* Willd. (60 days), *Eucalyptus deglupta* Blume (56 days), *Eucalyptus saligna* Smith (56 days) and *Pinus radiata* Schiede ex Schltdl. et Cham. (56 days). The kiln seasoning rate of timber from *A. polyacantha* is comparable with

Eucalyptus camaldulensis Dehnh. (5 days), *Albizia gummifera* (F. Gmel.) C.A. Sm. (5), *Albizia schimperiana* Oliv. (5), *Syzygium guineense* (Willd.) DC. (5) and E. *deglupta* Blume (7 days) (Getachew Desalegn *et al*., 2012).

Compared with air seasoning, kiln seasoning gave better possibility of controlling the relative humidity and temperature, MC, rate of seasoning, seasoning defects, appearance and the quality of seasoned timber besides reducing MC to the desired amount (about 12% MC) in a relatively very short period of time (Table 1). The applied kiln seasoning schedule (Ethiopia kiln seasoning schedule number 3) applied for this lumber species was suitable and achieved faster seasoning compared with air seasoning, and not much pronounced seasoning defects occurred.

Dimensional changes

Shrinkage and swelling characteristics: There was difference among the shrinkage characteristics of the sawn timber originated from Gibe and Konta sites. The mean tangential, radial, longitudinal and volumetric shrinkage percentage values of *A. polyacantha* timber from green (61%) to 12% MC for both Gibe and Konta sites were 4.3, 2.2, 0 and 6.3%, respectively. The mean tangential, radial, longitudinal and volumetric shrinkage percentage values for the lumber from green to seasoned condition (12% MC) were 3.9, 1.9, 0 and 5.7%, respectively, for the Gibe site lumber, and 4.8, 2.5, 0 and 7%, respectively, for Konta site. The mean shrinkage values of *A. polyacantha* timber from Gibe and Konta sites at oven dry MC were about 6.4, 2.8, 0 and 9%, respectively.

The ratio of mean tangential shrinkage to radial shrinkage of *A. polyacantha* from green to both 12% and oven dry MC was 1.96%. This means that mean tangential shrinkage of the species was 1.96 times higher than that of radial shrinkage. Compared to shrinkage values at 12% MC, seasoning to 0% MC was increased shrinkage values on average by more than 1.7 times. Wood shrinks about 1.5 to 2 times (Simpson, 1991) and more than half times (Denig et al., 2000) as much parallel to the growth rings (tangential) as it does at right angle to the growth rings (radial). The shrinkage along the grain (longitudinal) (Figure. 5) for this species was negligible. According to Simpson (1991) a species can have a small or negligible longitudinal shrinkage value.

The multiplying shrinkage coefficients for the tangential, radial shrinkage and volumetric shrinkage values of *A. polyacantha* lumber for each 1% MC reduction below 30% have been estimated for tangential and radial directions and volumetric as 0.24, 0.12 and 0.35, respectively. When the MC decreases, shrinkage value increases and the more difficult will be the lumber as a result of high shrinkage. Thus, care is needed for its rational utilization.

Based on the classification system adapted (Chudnoff, 1980), the tangential (4.2%) and radial (2.2%) shrinkage values of *A. Polyacantha* from green to 12% MC seasoning were classified as class 1, i.e., very low shrinkage value, indicating its good stabile quality. The tangential and radial shrinkage values obtained were falling within the range of shrinkage classes given for timber from different species, i.e., tangential shrinkage (3.5-15%), radial shrinkage (2.4-11%) and longitudinal (0.1-0.90%) (Kollmann and Côté, 1968).

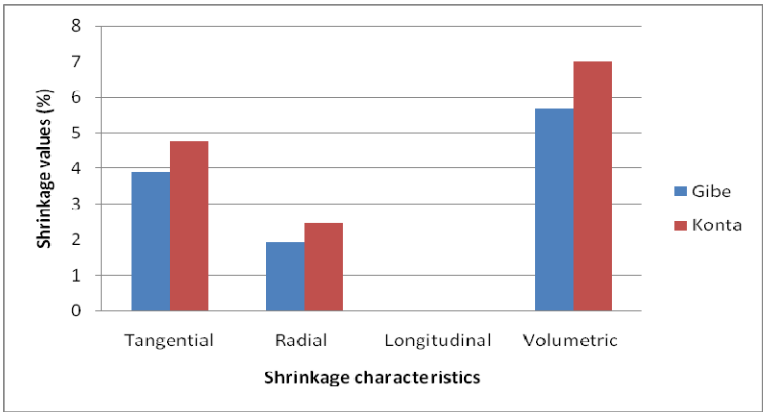

Figure 5. Shrinkage characteristic values (%) of *A. ployacantha* timber from green to 12% MC.

Tangential and radial shrinkage values of the species were fallen within the range of shrinkage classes given for timbers, i.e., tangential shrinkage (3.5-15%), radial shrinkage (2.4-11%) and longitudinal (0.1-0.90%) (Kollmann and Côté, 1968).

The mean tangential, radial, longitudinal and volumetric swelling percentage values from green (61%) to 12% MC for both sites lumber were 4.74%, 2.24%, 0%, and 7.20%, respectively. It revealed very low radial direction swelling value that may indicate good stability in service and high tangential swelling. The lower the shrinkage and swelling values, the better will be the species for the purpose intended. Lumber from Konta site revealed higher shrinkage characteristics from green to both 0% and 12% MC determined while lumber from Gibe site exhibited higher density values.

Seasoning defects and biodeterioration attack

Seasoning defects and rates recorded on Gibe site lumber were bow (3), twist (3), spring (2) and end split (3). However, spring was very slight. Defects recorded on Konta site lumber were cup (3), bow (2), spring (2), surface check (2), end check (3) and knots, where 1- none, 2- very slight, 3- slight, 4- moderate, 5- severe and 6- very severe seasoning defects (Longwood, 1961). Initially, on some boards of Konta sites wormholes and damages as well as knots were observed. This was recorded during tree felling and log sawing (Figure 6c).The tree is host of many insects and pests (Azene Bekele-Tesemma, 2007).

Important measures to minimize seasoning defects and shrinkage on *A. polyacantha* lumber are (i) proper stacking using stickers and top loading, where this can reduce cup, bow and twist. Stacking in a way that reduce rapid seasoning (end not facing the wind direction) will also minimize surface tension and the accompanying checking and distortion , (ii) applying stickers at < 3 cm narrow spacing, (iii) coating ends with a moisture-resisting paint or wax emulsion and applying slow seasoning schedule are recommended.

Appearance of *A. polyacantha* lumber

The freshly cut sapwood is whitish while the heartwood is light greenish brown. Thirakul (1993) also described the sapwood as white, heartwood red-brown with darker streaks, hard, heavy and with fine grain. *A. polyacantha* is an attractive, heartwood durable and much used species elsewhere (Hedberg and Edwards, 1989; Demel Teketay *et al*., 2010).

Storing and handling of post-seasoned lumber

Seasoned lumber of the species was piled board on board and without stickers and no top loading applied. Lumber was piled on a seasoning yard having supports of 45 cm from the ground. The observations made on seasoned and stored lumber for more than two years revealed that there was sever borer attack but no fungal and termite attack observed and recorded. No pronounced seasoning defects were observed after seasoning and during storing of the boards.

Density characteristics

Mean green (initial) and density at 12% MC of *A. polyacantha* lumber from both Gibe and Konta sites were 765 and 625 kg/m^3, respectively. Initial density and density at 12% MC of *A. ployacantha* lumber from Gibe site were 750 kg/m^3 and 640 kg/m^3, respectively (Figure. 6). Konta site lumber at 12% MC had initial and final density of 780 kg/m^3 and 610 kg/m^3, respectively. Gibe site had a relatively higher basic density and density at 12% MC (590, 640 kg/m^3) than Konta (550, 610 kg/m^3), respectively.

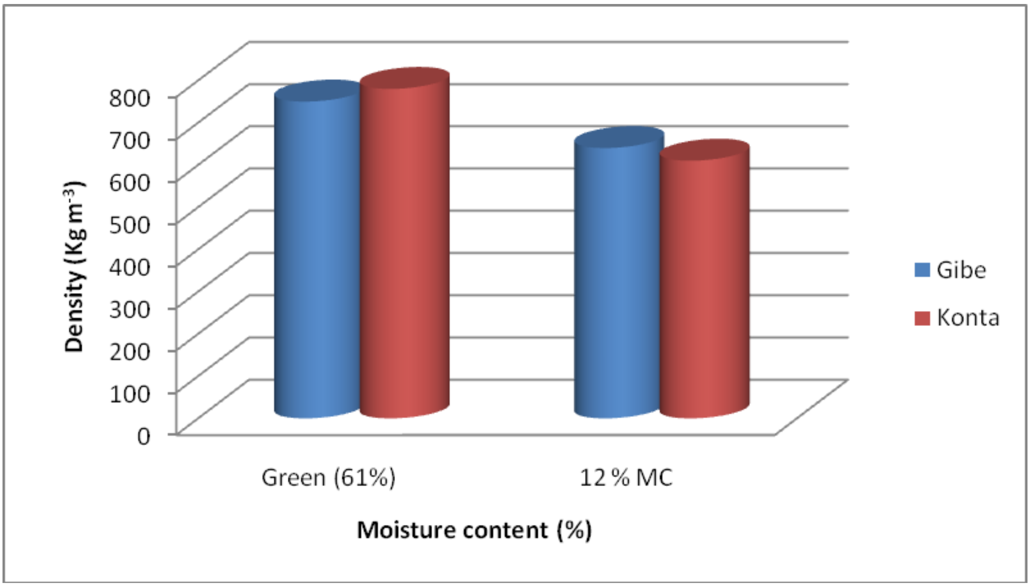

Figure 6. Green density and density at 12% MC of *A. polyacantha* lumber from Gibe and Konta sites.

There was difference in the density of sawn timber at different MC (Table 1). Lumber of *A. polyacantha* harvested from Gibe and Konta sites have a mean basic density (at dry weight and green volume) of 590 Kg/m^3 and 550 Kg/m^3, respectively.

The density value of *A. polyacantha* at 12% MC with an accuracy of ± 5% was comparable with other timber species, namely *Acrocarpus fraxinifolius* Wight and Am. (610 Kg/m^3), *Albizia grandibracteata* Taub. (600 Kg/m^3), *Eucalyptus dunii* Maiden (600 Kg/m^3), *Pouteria adolfi-friederici* (Engl.) Baehni (600 Kg/m^3). In general, *A. polyacantha* lumber from Konta site revealed higher MC, shrinkage characteristics and initial density values (WUARC, 1995; Getachew Desalegn, 1997; Getachew Desalegn and Wubalem Tadesse, 2010). In general, *A. polyacantha* lumber from Konta site revealed higher MC, shrinkage characteristics and initial density values.

Potential uses of Acacia polyacantha as lumber and non-timber forest products

The results from the studies on seasoning and density characteristics showed that A. polyacantha could be utilized as sawn timber for certain uses by substituting the endangered indigenous timber species, such as *Cordia africana* Lam., *Hagenia abyssinica* (Bruce) J.F. Gmel., *Juniperus procera* Hochst. ex Endl. and *Podocarpus falcatus* (Thunb.) R. B. ex Mirb. (TGE,1994), provided that care is taken during felling, sawing, stacking and seasoning of its timber and appropriate preservative treatments are carried out against fungal, beetle, borer and termite attacks.

The lumber of *A. polyacantha* can be used as agricultural implements, flooring, light and heavy construction, joinery, millwork, mine timbers, railway sleepers, beams and rafters, excellent firewood and charcoal, particleboard, plywood, poles, posts, railroad ties, sporting goods, tool handles, medicine (leaves, roots), fodder (leaves, pods) (Thirakul, 1993; Azene Bekele-Tesemma, 2007; Anonymous, 2009; Anonymous, 2012a). *A. polyacantha* is a species with many uses as for the genus *Acacia* and ash as a source of a salt substitute, and gums used in confectionary and adhesives (Hedberg and Edwards, 1989). The branch wood burns as fuel wood well, but the thorns make it difficult to handle.

The smell of the tree is useful repellent against snakes and crocodiles as poison. Used as medicine, a remedy for snakebite and as an infusion in which to bath children who are restless at night. In Tanzania and Zimbabwe, the roots have the reputation of possessing considerable magical properties (Anonymous, 2009).

Live tree uses includes shade and windbreak, nitrogen fixation, ornamental, soil improvement, live fence (Azene Bekele-Tesemma, 2007; Anonymous, 2009; Anonymous, 2012a).

Conclusions and Recommendations

A. polyacantha is an important fast growing and decorative timber tree species. Natural air and artificial kiln seasoning methods revealed good timber characteristics including seasoning, density, appearance, and shrinkage characteristics, and low seasoning defects but high deterioration with borer attack. The density values were comparable with some indigenous and homegrown exotic timbers grown in the country.

The following recommendations are forwarded regarding the different lumber characteristics and rational utilization of *A. Polyacantha*: (i) *A. polyacantha*, which is prone to various forms of distortion have to be seasoned carefully and slowly, (ii) applying proper stacking methods including stickers and top loading, (iii) kiln seasoning using appropriate schedule have to be used, if lower MC at faster seasoning rate below 30% and minimizing of shrinkage and seasoning defects are required, (iv) control measures have to be taken into account against MC level (≥ 12% to ≤ 20%) for outdoor construction, and 8-12% for indoor construction, joinery and furniture purposes). Proper MC, shrinkage and swelling allowances and density values have to be considered before installing and/or manufacturing lumber and other wood-based products from this timber species, (v) applying lumber for ground and moisture contact construction, joinery and furniture purposes strongly entails application of appropriate preservative measures, and (vi) medium and large-scale tree planting activities of the species with good silvicultural management practices to improve yield, increase wood quality and control area coverage not to become aggressive worrier due to its high natural regeneration capacity, to obtain high recovery rate and quality lumber.

Therefore, the timber species has to be grown and well managed. Lumber have to be properly seasoned to the appropriate MC for the purpose and environment of application (≤ 20% to 0% MC), with a method (air or kiln) that can help minimize seasoning defects and shrinkage characteristics and increase quality and serviceability of the lumber species. It has to be stored, manufactured and warehoused/handled at humidity conditions that are at or slightly below the expected in- use humidity conditions, and rationally utilized at specific MC, density and other basic wood characteristics for intended construction, furniture and wood-based energy purposes.

Proper seasoning, post-harvest handling, and storing of the lumber of *A. polyacantha* improve the characteristics, which will ensure quality of the products and enhance rational utilization of the species as one competent and alternative source of construction and furniture material in the country. The species has to be further studied for its timber characteristics, quality and to be promoted for large-scale plantations and rational utilization in Ethiopia.

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Yield and Nutrient Composition of Pleurotus *Sajor caju* on Various Substrates

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Introduction

Pleurotus species (oyster mushrooms) are common and primary wood and other lignocellulosic decaying fungi. They grow naturally in the wild in tropical and subtropical rainforests and also commercially cultivated (Bonatti et al., 2004). They can grow in a wide range of temperatures (Gawley, 1983; Khan and Garcha, 1984; Mueller). They have extensive enzymatic systems and are among the most efficient white rot fungi and as a result various forest biomasses and agricultural wastes can be utilized to grow them (Platt et al., 1984). Oyster mushrooms cultivation is becoming popular throughout the world (Chang, 1999; Kues and Liu, 2000). However, there are only few reports indicating establishment and expansion of mushroom farms in Africa (Dawit, 1998; Justus, 2004; Ukoima et al. 2009).

Amount, abundance and comparative suitability of accessible lingo-cellulosic materials has to be explored for the indoor cultivation of mushrooms. Bush biomass, especially the biomass of aggressive rangeland encroaching acacias, are one of the viable substrates available in abundance. This biomass is particularly available in excess in the Borana rangelands (Alemayehu 1998; Oba 1998; Tesfaye *et al*. 2004). *Acacia* species are among those aggressively encroaching native plant species in the rangeland. Therefore, utilization of this locally unwanted and noxious bush biomass for mushroom cultivation has two fold benefits: re-growth of grasses for their cattle and cultivation of mushrooms. The other potential lingo-cellulosic substrate sources for mushrooms growing are wood industry wastes and coffee processing areas. Therefore, this study was conducted with the objective to screen some suitable biomasses for oyster mushroom (*P. sajor-caju*) cultivation. Therefore, the objective of this study was to screen some suitable biomass-based species for oyster mushroom cultivation.

Materials and Methods

Spawn Production

The spawn was prepared following the procedures stated in Pakale (2004).

Substrates Preparation and Cultivation

Different potential substrates processed for mushroom cultivation. The substrates were Acacia species (*A. drepanolobium*, *A. melifera* and *A. seyal*), coffee husk, sawdust (*Pouteria adolfi-friedericii* and *Cupressus lustanica)*, and agricultural residues *(Triticum aestivum* [wheat], *Eragrostis tef* [tef] and *Hordeum vulgare* [barely] straws). The branches and stems of acacia species and the straws were chopped at 3-5 cm length manually. The substrates were processed according to Bonatti et al. (2004) both in pure and mixture and filled into polyethylene bags with five replications (Table 1). The bags with the substrates were pasteurized, cooled overnight and then spawned. The bags were then incubated at room temperature and 65% relative humidity (RH). After complete mycelia colonization, the RH was increased to 90% using humidifiers for induction of fruit bodies and cultivation.

Data collection and analysis

The yield of the mushroom was determined at the event of collecting three flushes of fruit-bodies' harvest. The average biological efficiency (BE) was quantified as total weight of mushrooms harvested per dry weight of the substrate. The fruit-body yield in terms of biological efficiency (BE) was analyzed. The nutrient compositions of the pure substrates were also analysed. The differences existing between the means of the yield and nutrient compositions were evaluated for significance using the Duncan's test at 5% level using statistical software SPSS vs. 12.0.

Table 1. Acronym for substrate type and mixing ratios

Code	Description of the mixing substrates	Mixture ratio
DC	Chopped *A. drepanolobium*	Pure
DCAS1	Chopped *A. drepanolobium* mixed with *Pouteria adolfi-friedericii* sawdust	9:1
DCAS2	Chopped *A. drepanolobium* mixed with *P. adolfi-friedericii* sawdust	8:2
MC	Chopped *A. melifera*	Pure
MCAS1	Chopped *A. melifera* mixed with *P. adolfi-friedericii* sawdust	9:1
MCAS2	Chopped *A. melifera* mixed with *P. adolfi-friedericii* sawdust	8:2
SC	Chopped *A. seyal*	Pure
SCAS1	Chopped *A. seyal* mixed with *P. adolfi-friedericii* sawdust	9:1
SCAS2	Chopped *A. seyal* mixed with *P. adolfi-friedericii* sawdust	8:2
TS	Chopped tef straw	Pure
BS	Chopped barley straw	Pure
WS	Chopped wheat straw	Pure
CH	Coffee husk	Pure
CHAS1	Coffee husk mixed with *P. adolfi-friedericii* sawdust	7:3
CHAS2	Coffee husk mixed with *P. adolfi-friedericii* sawdust	6:4
CHAS3	Coffee husk mixed with *P. adolfi-friedericii* sawdust	5:5
CHAS4	Coffee husk mixed with *P. adolfi-friedericii* sawdust	4:6
CHAS5	Coffee husk mixed with *P. adolfi-friedericii* sawdust	3:7
AS	*P. adolfi-friedericii* sawdust	Pure
CHCS1	Coffee husk mixed with *C. lustanica* sawdust	7:3
CHCS2	Coffee husk mixed with *C. lustanica* sawdust	6:4
CHCS3	Coffee husk mixed with *C. lustanica* sawdust	5:5
CHCS4	Coffee husk mixed with *C. lustanica* sawdust	4:6
CHCS5	Coffee husk mixed with *C. lustanica* sawdust	3:7
ASCS1	*P. adolfi-friedericii* sawdust mixed with *C. lustanica* sawdust	7:3
ASCS2	*P. adolfi-friedericii* sawdust mixed with *C. lustanica* sawdust	6:4
ASCS3	*P. adolfi-friedericii* sawdust mixed with *C. lustanica* sawdust	5:5
ASCS4	*P.. adolfi-friedericii* sawdust mixed with *C. lustanica* sawdust	4:6
ASCS	*P. adolfi-friedericii* sawdust mixed with *C. lustanica* sawdust	3:7
CS	*C. lustanica* sawdust	Pure

Results and Discussion

Biological Efficiency (BE)

BE of the substrates indirectly denotes the substrates' suitability to support growth of a given mushroom. The higher the BE, the greater will be the suitability of the substrate. Table 2 demonstrates that, among the types of substrates tested, chopped *A. drepanolobium* showed the best results in biological efficiency (BE). The result was found to be significantly higher than those obtained for other substrates except the barley straw (BS). Similar to the finding obtained for the mycelial colonization (data not shown), the lowest BE was obtained for the mixture of ASCS4 (Table 2). The biological efficiency of CH was one of the lowest and its mixtures with AS and CS were the smallest in comparison with other mixture-substrates. The AS and CH mixture-substrate showed a decrease in biological efficiency as the amount of AS was increased.The pure CS and ASCS (3:7) did not yield any fruit-body which is in good agreement with the finding of Croan (2004).

Table 2 further showed that CS's mixture with CH and AS was also belonged to the lowest in BE. It can be observed that, as the proportion of CS was increased, the BE of the mixture happened to be reduced. Poor BE in this case is most probably due to the CS extractives which hindered/lowered the mycelia colonization. WS showed equivalent efficiency when compared to BS and DC substrates. The BE of WS and its mixtures reported by various studies range widely from 50.2% to 97% (Zhang et al., 2002; Salmones et al., 2005). In this study, the BE of *P. sajor-aju* on WS is less than the one reported by Zhang et al *al*. (2002) but it was better than the report of Salmones et al. (2005). Banik and Nandi (2004), reported 89.2% BE on rice straw for *P. sajor-caju*.

Mean values within the same column with no common superscript letter differ at the 95% confidence level and the corresponding numbers indicate the mean values; [1]Results reflect observations of five replications; [2]Standard deviation; Values are means of five replicates±SD

BE reports of Salmones et al. (2005) for *P. austreatus* and Bermudezet al. (2001) for *P. florida* on CH were higher than the one obtained in this study on the same substrate. Therefore, coffee husk is more suitable for the cultivation of *P. austeatus* and *P. florida* than it is for *P. sajor-caju*. The biological efficiencies of DC, DCAS1, DCAS2, SC, SCAS1, SCAS2, TS, BS and WS were higher than those reported by Ragunathan and Swaminathan (2003) for cotton stalk, coir fibre and sorghum stoker. However, the biological efficiencies of MC, MCAS1, CH, CHAS1, CHAS2, CHAS3, CHAS4 and CHAS5 and AS were equivalent to results reported by Ragunathan and Swaminathan (2003). In general, mixing of AS with acacia and coffee husk substrates lower the biological efficiency of the substrate to 30% and the worst substrate mix become the CS, which significantly reduced the mushroom yield in all substrates it was mixed with.

Table 7: Yield results of *P. sajor caju* cultivated on different substrates.

Substrate	FB/Bag[1] Mean±SD[2]	Yield (g)/kg[1] Mean±SD[2]	BE (%)[1] Mean±SD[2]
DC	563.65 ± 4.28^{a}	854.11 ± 24.93^{a}	85.41 ± 2.49^{a}
DCAS1	430.12 ± 3.97^{c}	703.99 ± 48.51^{d}	70.39 ± 4.85^{d}
DCAS2	368.73 ± 3.87^{e}	594.78 ± 42.36^{f}	59.47 ± 4.23^{f}
MC	248.29 ± 2.09^{k}	342.64 ± 20.11^{ij}	34.26 ± 2.00^{ij}
MCAS1	191.3 ± 2.64^{m}	321.58 ± 13.00^{ijkl}	32.15 ± 1.30^{ijkl}
MCAS2	149.45 ± 1.27^{qr}	248.59 ± 3.54^{m}	24.86 ± 0.35^{m}
SC	535.49 ± 2.13^{b}	790.03 ± 19.74^{c}	79.00 ± 1.97^{c}
SCAS1	396.24 ± 1.52^{d}	715.78 ± 37.88^{d}	71.57 ± 3.78^{d}
SCAS2	284.79 ± 2.47^{ij}	645.73 ± 10.47^{e}	64.57 ± 1.04^{e}
TS	94.11 ± 2.02^{v}	518.41 ± 13.11^{g}	51.84 ± 1.30^{g}
BS	161.04 ± 4.17^{p}	835.66 ± 14.94^{ab}	83.56 ± 1.49^{ab}
WS	$152.05 \pm .89^{q}$	812.50 ± 13.03^{bc}	81.25 ± 1.30^{bc}
CH	361.23 ± 5.12^{f}	390.16 ± 7.28^{h}	39.01 ± 0.73^{h}
CHAS1	341.68 ± 1.59^{g}	359.09 ± 3.61^{hi}	35.91 ± 0.36^{hi}
CHAS2	334.87 ± 2.10^{g}	341.01 ± 3.78^{ijk}	34.10 ± 0.37^{ijk}
CHAS3	319.36 ± 1.49^{h}	324.01 ± 3.66^{ijkl}	32.40 ± 0.36^{ijkl}
CHAS4	312.87 ± 2.85^{h}	315.45 ± 2.94^{jkl}	31.54 ± 0.29^{jkl}
CHAS5	287.46 ± 5.21^{i}	301.12 ± 7.22^{kl}	30.11 ± 0.72^{kl}
AS	278.64 ± 3.23^{j}	291.26 ± 2.36^{l}	29.12 ± 0.23^{l}
CHCS1	206.28 ± 4.84^{l}	213.64 ± 15.60^{mn}	21.36 ± 1.55^{mn}
CHCS2	183.39 ± 3.47^{o}	191.91 ± 4.19^{no}	19.19 ± 0.42^{no}
CHCS3	146.19 ± 4.59^{qrs}	150.31 ± 3.04^{p}	15.03 ± 0.30^{p}
CHCS4	140.27 ± 1.57^{s}	144.26 ± 2.29^{p}	14.42 ± 0.22^{p}
CHCS5	120.97 ± 2.07^{t}	123.87 ± 3.20^{p}	12.38 ± 0.32^{p}
ASCS1	186.60 ± 2.97^{no}	197.52 ± 4.07^{n}	19.75 ± 0.40^{n}
ASCS2	142.65 ± 3.05^{rs}	153.91 ± 6.83^{op}	15.39 ± 0.68^{op}
ASCS3	127.42 ± 1.63^{t}	133.52 ± 0.83^{p}	13.35 ± 0.08^{p}
ASCS4	110.81 ± 1.88^{u}	116.49 ± 2.87^{p}	11.64 ± 0.28^{p}

Nutrient composition of the fruit bodies

Some of the elements which are essential for the human metabolism (K, Na, Fe, Mn, Cu and Zn) (Istihi et al. 2009) were measured. The results indicated significant variations in both the micro and macro elements against the different test substrates. There was a lower ash content in the fruit bodies of the two agricultural straws (TS and BS), DC and AS. On the other hand, ash content of the fruit bodies of WS, DC, AS and CH were not varied. Ragunathan and Swaminathan (2003) reported the ash content of 5.59% on rice straw and 5.14% on banana straw for the same mushroom species. Pushpa and Purushothama (2010) reported 9.41% ash content of *P. Florida* cultivated on. As to the individual mineral contents of the fruit bodies, the K contents of the fruit bodies of the different substrates were not varied except AS which was significantly less than all. Similarly, the Na contents due to the utilization of different substrates showed no significant variation except that DC contained statistically higher and TS. Generally, the acacias resulted in higher Fe contents of the fruit bodies than the agricultural residues. The Mn contents of the fruit bodies from the agricultural residues were higher than those cultivated using the acacias. It is also an interesting observation that there were higher Cu and Zn contents in the fruit bodies from agricultural residues than the woody biomasses. Banik and Randi (2004) reported 2.9% for K and 0.32% for Na on rice straw, which is lower than the findings of this work. This result is slightly higher than this report. The author also reported 0.00105% for Cu, 0.0015% for Mn and 0.0115% for Zn on chemithermo-mechanical pulp.

The organic matters contained in the fruit bodies collected from the different substrates were not varied. The crude protein (CP) content of the agricultural residues and AS was significantly less than those from the acacias. Pushpa and Purushothama (2010) also reported 27.81% protein content for *P. flrida* that is much less, than the result obtained in this research. Non-digestible fibre (NDF) of fruit bodies from CH was significantly higher than all other substrates but Ether extract (EE) contents were almost the same in all treatments. It seems that the acacias helped the mushroom fruit bodies to accumulate more N and P than the other remaining substrates. Finally, it was observed that, the gross energy that can be generated from the woody biomass was higher than those from the agricultural residues.

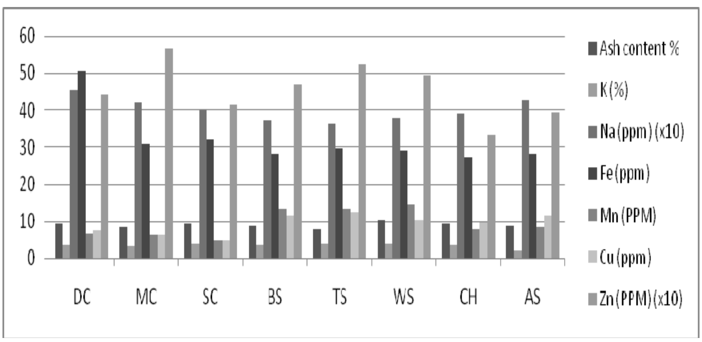

Figure 1.Some of the micro and macro minerals from the fruit bodies of P. sajor-caju mushroom cultivated on different substrates.

Key: Ad = Acacia repanolobium, AM = A. melifera, AS = A. seyal, BS=barley straw, TS=tef straw, WS=wheat straw, CH=coffee husk, AS= P. adolfi-friedericii

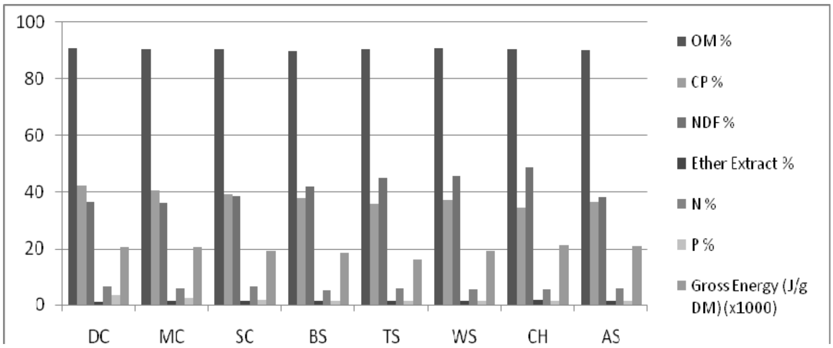

Figure 2. Organic content and energy of the fruit bodies of *P. sajor-caju* mushroom cultivated on different substrates.

Conclusion

This study showed that chopped *Acacia drepanolobium* has the highest biological efficiency followed by barley straw, wheat straw and *Acacia seyal* in decreasing order. Generally, the *Acacia* species performed well for mushrooms cultivation. It was observed that *Cupressus* and *P. adolfi-friedericii* sawdust were not suitable substrates for the growth of *P. sajor-caju* and care should be taken in sawmills not to mix the sawdust with other lingo-cellulosic wastes intended for mushrooms cultivation. Therefore, the abundantly available encroaching *Acacia* species indicated above and found in the Borana rangeland can be used for the cultivation of oyster mushrooms.

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Closing Remarks

Teklehamanot Nigatu,
General Manager of Natural Gum Processing and Marketing Enterprise (NGPME)

First on behalf of the Natural Gum Processing and Marketing Enterprise (NGPME) and myself I thank the workshop organizers and the Ethiopian Institute of Agricultural Research, Forestry Research Directorate (EIAR-FRD) for their invitation to participate in this workshop and deliver a closing remark. I also thank the researchers for their excellent work and the participants for their valuable inputs during the workshop sessions and general discussion time.

As long as I was there at the opening session and as per the report, I got from my colleagues, the workshop was very valuable in general to the Forestry Sector and more specifically to the NTFPs and/or Gum and Resins sub- sector. As you well know, NGPME is fully engaged in the production, processing and marketing of Natural Gums like Gum Olibanum, Gum Arabic, Gum Myrrh and Gum Oppoponex. It has around 40% share of the country's export. It has also been engaged in the conservation, development, and research activities of forests especially natural gum bearing forests. Since 2007, it has aggressively been involved in these activities and expending at average half a million birr every year. It is working in collaboration with research institutes, universities and various NGO's. It has also been providing research problems and ideas, data/information, very small promotional funds and expertise.

Though a lot of research works are going on, there is still very big gap in technologies dissemination especially in NTFPs and/or Gum and Resins sub-sector. Our enterprises' five year and so development and research effort, with few exceptions, did not give us the intended result. This is mainly due to lack of a viable technology. There is rather a very frustrating research outputs when we see it from business, environmental and ecological points view. The danger in *Boswellia papyrifera* is the major one. News like ''Frankincense production will be reduced by 50% in 15 years time; ''Mature trees of *B. papyrifera* age will possibly reach 50-60 years'; ''No regeneration of *B. papyrifera''*; ''Development of *B. papyrifera* through seedling not successful'' ……etc are very frustrating research gaps. However, I have strong belief that the ways we are now handling this issue give me some hope that our strong and coordinated efforts will give us the intended results. In this endeavor, our enterprise fully supports and ready to work together with any intensive and extensive research work towards finding a solution to the danger that we are facing now.

Finally, I thank all of you once again and hereby declare the workshop is officially closed.