ESCUELA TÉCNICA SUPERIOR DE INGENIERÍAS AGRARIAS
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DOCTORAL DISSERTATION / TESIS DOCTORAL

# Underutilized Non-Timber Forest Products in Ethiopia; socioeconomic, status and yield potential

# Productos forestales no madereros infrautilizados en Etiopía; potencial socioeconómico, de estatus y de rendimiento

Presentada por Gizachew Zeleke Adugna
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Underutilized Non-Timber Forest Products in Ethiopia: socioeconomic, status, and yield potential

Productos forestales no madereros infrautilizados en Etiopía: socioeconómico, estado y potencial de rendimiento


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# Dedication

To my mother Seleshi Desalegn (*Eye'a*) and my sister Yeshi Zeleke

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## Abstract

Ethiopia is rich in biodiversity; however, the diversity of plants is highly threatened. Consequently, many of the Non-Timber Forest Products (NTFPs) with significant potential for rural livelihood improvement are unvalued, underutilized, and threatened. Moreover, the NTFPs are neglected and not included in Ethiopia's forest management plans and strategies. Then again, location based specific studies related to the NTFPs production are scarce in the country. They would be key to assist the rural communities in their food security and income generation through the sustainable management, use and conservation of valuable species strategies in their natural habitat. Thus, in this doctoral thesis, we aimed to generate information on the socioeconomic, population status, and yield potential of underutilized NTFP producing tree species and wild edible mushrooms in Ethiopia. For this purpose, we targeted the valuable but underutilized NTFP such as wild mushrooms, *Tamarindus indica* fruits and *Senegalia senegal* gums*.* In this study, we did the ethnomycological socioeconomic, vegetation inventory and yield estimation studies. The socio-economic survey was conducted to collect information related to wild mushrooms by using semi-structured interviews with members of the Amhara, Agew, and Sidama ethnic groups. Forest inventories were also undertaken to investigate mushroom growing habitat and to identify useful wild mushroom species in each study area. In total, 300 households were surveyed. In the vegetation survey of the *T. indica*, we evaluated the stand status, dendrometric variables, and fruit production of Tamarind trees growing in bushland- and farmland-use types in dryland areas of Dello Menna district, Ethiopia. In this case, we used the point-centered quarter method and the tree density per ha and the fruit yield were evaluated. Predictive models were used for Tamarind fruit yield estimations. Furthermore, we also evaluated the population status and potential gum yield of *Senegalia senegal* growing in the dryland areas of South Omo Zone, Ethiopia. Forty-five sample plots, each measuring 20 × 20 m, were established at 500 m intervals along transects, with 1 $m^2$ subplot located within the main plots to determine regeneration. A linear model of dendrometric variables was used to estimate gum production from individual *S. senegal*. From the results of the socio-economic survey, we found that the Sidama ethnic groups have the most extensive ethnomycological knowledge of mushrooms as compared to the Amhara and Agew ethnic groups. A total of 24 useful wild mushrooms were identified. In the Amhara and Agew ethnic groups, wild mushrooms consumption is not common. However, they indicated that their ancestors were used to eating wild mushrooms, which could eventually represent a loss of mycological knowledge in these two ethnic groups. On the other hand, such inconsistency between ethnic groups in terms of their knowledge and perception may also be linked to the social valuation of mushroom resources, which could easily be mitigated by raising awareness. Similarly, the vegetation survey of Tamarind revealed that there was a significant difference in Tamarind tree density between the two land-use types ($p = 0.01$). The mean fruit yield of farmland trees was significantly higher than that of bushland trees. However, Tamarind has an unsustainable stand/age structure in the farmlands. Differences in the dendrometric characteristics of trees were also observed between the two land-use types. Although higher Tamarind fruit yields were obtained from trees growing on farmland than in bushland in the Dello Menna district, the majority of farmland trees produced <5000 fruit per tree, and their yield can be improved through deliberate selection of higher fruit yielder trees. This strategy might also lead to the development of a sustainable fruit supply in rural areas for commercialization or subsistence use. Similarly, the vegetation survey of *Senegalia senegal* indicated the presence of forty-two tree species, of which 16 were gum- and resin-producing tree species. *Senegalia senegal* comprised approximately 35% of regenerating trees. The maximum gum arabic yield obtained was 3948 g $tree^{-1}$. Linear models of dendrometric variables indicated that gum arabic yield is better predicted by tree diameter than by height. The information obtained through the socioeconomic study could be useful for further investigations, and for promoting ethnomycological benefits to different ethnic groups in countries with similar settings. The information generated from the vegetation survey of the *Tamarindus* trees could also help rural communities in areas that are facing similar challenges for valuable trees due to land-use change as well as for the development of management plans to establish stands that have a more balanced diameter structure and thereby ensure continuity of population and fruit yields. Similarly, the information gathered from *S. senegal* study could help to safeguard the longevity and the proliferation of valuable NTFP-producing tree species in lowland areas, as well as the livelihoods supported by these resources, both in the study area and country-wide. Generally, the findings in the three studies could provide management support to conserve the forests resources in Ethiopia through adding economic value from the NTFPs production and utilization while enhancing the livelihood of local communities.

Keywords: Ethiopia, Non-Timber Forest Products, *Tamarindus indica*, *Senegalia senegal*, Wild mushroom

## Resumen

Etiopía es un país muy rico en biodiversidad, pero ésta se encuentra muy amenazada. Muchos productos forestales no maderables (PFNMs) con un potencial significativo para mejorar los medios de vida rurales no están valorados, están poco aprovechados y/o están amenazados. Los PFNMs son subestimados y no están incluidos en planes y estrategias de manejo forestal de Etiopía. Por otra parte, hay muy pocos estudios centrados en especies productoras de PFNMs que podrían proporcionar seguridad alimentaria y generar ingresos a través de su recolección, consumo y comercialización sostenible. Además, no existe una estrategia de conservación adecuada que evite el agotamiento y la pérdida del hábitat natural en el país. Por lo tanto, el objetivo de este estudio fue generar información sobre el estado socioeconómico, el potencial de producción de PFNMs infrautilizados en Etiopía. Se tomaron en consideración los hongos silvestres, el fruto del tamarindo (*Tamarindus indica*) y la resina obtenida de *Senegalia senegal*. La información socioeconómica sobre hongos silvestres se recopiló mediante la realización de entrevistas semiestructuradas con comunidades de los grupos étnicos Amhara, Agew y Sidama. También se realizaron investigaciones en campo para conocer el hábitat e identificar especies de setas silvestres útiles. En total, se desarrollaron encuestas en 300 hogares. Para el estudio de la vegetación de *T. indica,* se evaluó el estado de los rodales, las variables dendrométricas y la producción de frutos de los árboles que crecen tanto en zonas naturales matorralizadas como en tierras agrícolas, en una zona seca del país. Para seleccionar los árboles muestreados se aplicó el método del cuadrante centrado en un punto. También se evaluó la densidad de árboles por ha y la producción de frutos. Se utilizaron modelos predictivos para las estimaciones de la producción de frutos de Tamarindos. Además, se evaluó el estado de una masa forestal dominada por *Senegalia senegal* y su producción potencial de goma arábica, en la Zona Sur de la Región Omo de Etiopía. Se establecieron 45 parcelas de muestreo, cada una de 20 × 20 m, a intervalos de 500 m a lo largo de los transectos, con subparcelas de 1 $m^2$ ubicadas dentro de las parcelas principales para determinar la regeneración. Se utilizó un modelo lineal para estimar la producción de goma arábica en base a distintas variables dendrométricas. El estudio ethnomicológico socioeconómico reveló que la población en Sidama tiene el conocimiento más extenso sobre el recurso micológico. Se identificaron un total de 24 especies útiles de hongos silvestres. Los ancestros de los grupos étnicos Amhara y Agew consumían setas silvestres, aunque actualmente no se consumen, lo que eventualmente podría representar una pérdida de conocimiento micológico. Esta incoherencia entre los grupos étnicos en términos de su conocimiento y percepción también puede estar relacionada con la valoración social del recurso micológico, que podría mitigarse mediante la sensibilización. De manera similar, el estudio de reconocimiento o muestreo de vegetación de Tamarindo reveló que había una diferencia significativa en la densidad de árboles de Tamarindo entre los dos tipos de uso de la tierra ($p$ = 0.01). La producción media de frutos de los árboles en las tierras de cultivo fue significativamente mayor que la obtenida de los árboles que crecía en zonas matorralizadas. Sin embargo, la estructura de edades de Tamarindo en las tierras de cultivo tiene una estructura insostenible por falta de regeneración y plantas en edades jóvenes. Se obtuvieron mayores rendimientos de fruta de tamarindo de los árboles que crecen en tierras agrícolas que en los matorrales en el distrito de Dello Menna. La mayoría de los árboles de las tierras agrícolas produjeron <5000 frutas por árbol. La selección de germoplasma de tamarindo en sus áreas de distribución naturales podría mejorar dicha producción. Por otro lado, el estudio de reconocimiento o muestreo de vegetación de *S. senegal* indica que cuarenta y dos especies de árboles estaban asociadas con esta especie principal, de las cuales 16 especies son productoras de goma y resina. *Senegalia senegal* comprendía aproximadamente el 35% de los árboles en regeneración. La producción máxima de goma arábiga obtenida fue de 3,948 g árbol$^{-1}$. Los modelos lineales indicaron que la producción de goma arábica se predice mejor por el diámetro del árbol que por la altura. La información pionera obtenida del estudio socioeconómico podría ser útil para futuras investigaciones y para promover los beneficios etnomicológicos a diferentes grupos étnicos en países con entornos similares. De manera similar, los resultados del estudio de vegetación de árboles de Tamarindo podrían ayudar a identificar áreas que enfrentan desafíos similares para la especie debido al cambio de uso de la tierra, así como para el desarrollo de planes de manejo que permita conseguir rodales con estructuras diamétricas más equilibradas y de ese modo garantizar la continuidad de la población y por tanto la producción de frutos. Por otro lado, la información recopilada a partir de la investigación de *S. senegal* podría ayudar a salvaguardar la longevidad y la proliferación de valiosas especies arbóreas productoras de PFNMs en las zonas bajas de Etiopía, así como los medios de vida sostenidos por estos recursos, tanto en el área del estudio como en todo el país. En general, los resultados de estos estudios también podrían proporcionar implicaciones de gestión para conservar los recursos forestales en Etiopía mediante la adición de valor económico de los PFNMs al tiempo que se mejora el sustento de las comunidades locales.

Palabras claves: Etiopía, productos forestales no madereros, *Tamarindus indica*, *Senegalia senegal*, setas silvestres

## List of original articles

Three original articles have been generated from this thesis work. All of them are already published in Science Citation Index (SCI) journals. Authors, coauthors, and details of the publication are presented below:

I. **Gizachew Zeleke, Tatek Dejene, Wubalem Tadesse, Dolores Agúndez and Pablo Martín-Pinto, 2021.** Ethnomycological knowledge of three ethnic groups in Ethiopia. ***Forests*** 11: 875. https://doi:10.3390/f11080875

II. **Gizachew Zeleke, Tatek Dejene, Wubalem Tadesse and Pablo Martín-Pinto, 2021.** Land-use impact on stand structure and fruit yield of *Tamarindus indica* L. in the drylands of Southeastern Ethiopia. ***Life*** 11: 408. https://doi.org/10.3390/life11050408

III. **Gizachew Zeleke, Tatek Dejene, Wubalem Tadesse and Pablo Martín-Pinto, 2021.** Gum arabic production and population status of *Senegalia senegal* (L.) Britton in Dryland forests in South Omo Zone, Ethiopia. ***Sustainability*** 13: 11671. https://doi.org/10.3390/su132111671

## Outline of the thesis

This doctoral thesis consists of three research studies important to promote and conserve the neglected and underutilized NTFPs in Ethiopia. Thus, in this thesis we used both the socioeconomic, vegetation and yield inventories in order to evaluate the status of NTFPs and to device proper management to get their conservation and sustainable use. From the utilization aspects of NTFPs, the first study was focused on ethnomycological aspects of wild edible mushrooms based on ethnic groups' factors influencing the collection, use and consumption, and other perceived status and threats to wild mushrooms in their vicinity. In this study, valuable wild mushroom species were identified. The perceived value of wild mushroom was recorded. The consumption of wild mushroom by householders was investigated. The status of wild mushroom species was evaluated, and the main threats and how these threats vary across the three ethnic groups were also identified. Thus, the baseline information obtained could be useful for further investigations and for promoting the ethnomycological knowledge to different ethnic groups in countries with similar settings.

From the perspective of NTFPs conservation and production, the second study was focused on the evaluation of the impact of land uses on the stand structure and on the fruit yield of *Tamarindus indica* trees growing in bushland- and farmland-use types in the dryland areas of Ethiopia. In this study, the information related to species composition, densities and stand structure, dendrometric variables that influence Tamarind fruit production were analyzed. The predictive models were calculated to estimate Tamarind fruit yield in the study areas. The information generated from this study provides baseline information that can be used to promote the conservation and sustainable use of Tamarind trees and other valuable wild edible tree species under different land-use types in Ethiopia. Also, the information generated could assist other countries with valuable wild trees that are facing similar issues due to land-use change.

From the commercialization aspects of NTFPs, the third study was focused on the evaluation of the population status and potential gum yield of *Senegalia senegal* growing in dryland areas of the South Omo Zone, Ethiopia. In this study, the associated species with *S. senegal* trees were identified. Also, the current status *S. senegal* trees, their gum arabic yield potential estimation and dendrometric variables that affect gum yield were evaluated. The information gathered in this study could help to safeguard the longevity and the proliferation of NTFP-producing tree species in lowland areas of the county, as well as the livelihoods supported by these resources, both in the study area and country-wide. In general, the findings from the three studies that constituted this thesis may support the management, conservation, and utilization of underutilized non-timber forests products in the county. This could also facilitate the community utilization and commercialization of the targeted species based on their potentials through adding the value of the forests. Conceptual map of the study including the three studies is shown below in Figure 1.

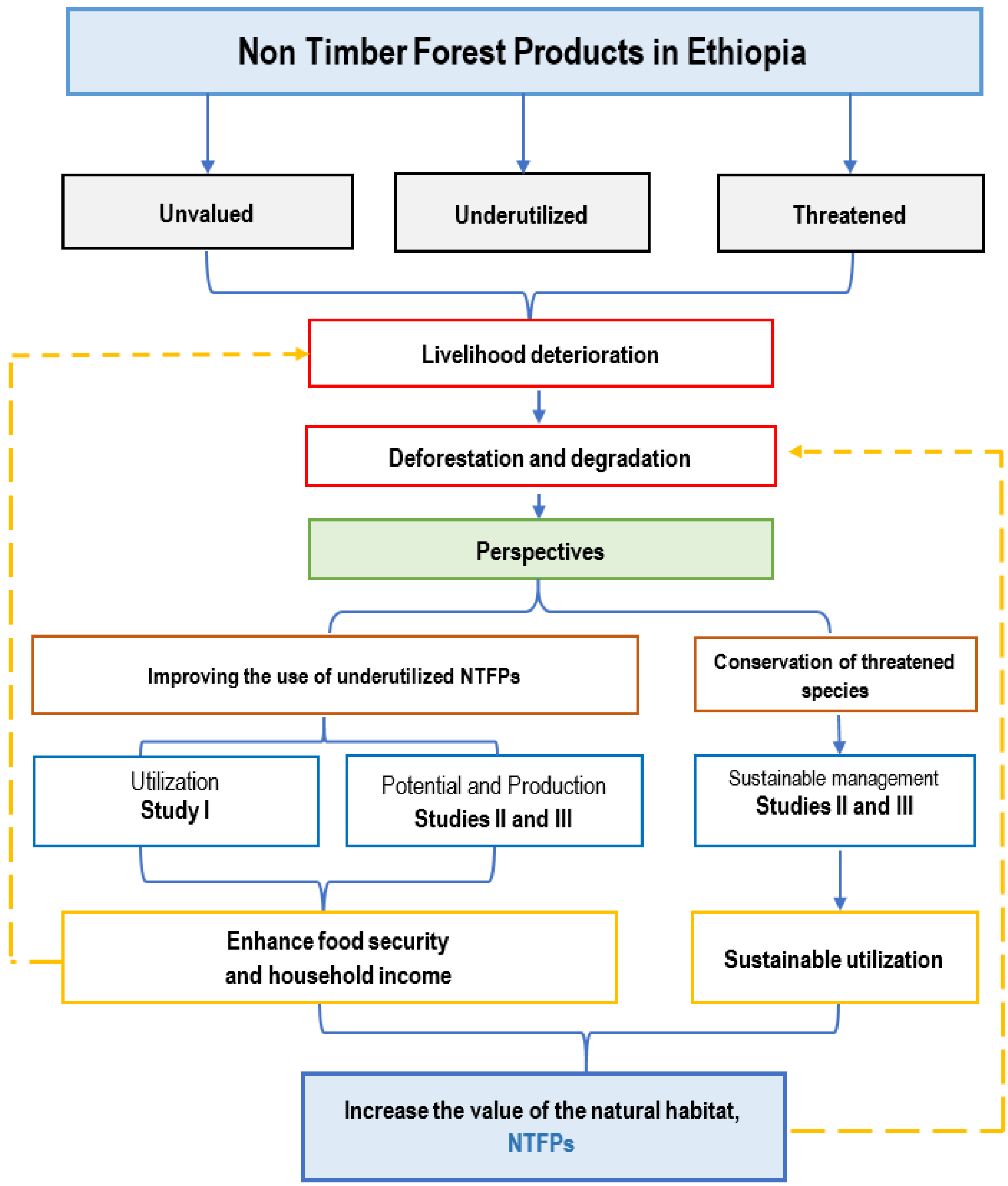


Figure 1: Conceptual map of the thesis including the three studies.

# *Introduction*

# 1. Introduction

## 1.1. Forest resources in Ethiopia

In Ethiopia, the wide array of altitudinal gradients and the varying topographic features have created quite diverse ecological conditions (Bongers and Tenngkeit, 2010). Also, the country experiences a very high variation in macro and micro-climatic conditions which have contributed to the formation of diverse ecosystems inhabited with a great diversity of life forms in flora and fauna. Furthermore, the mean annual rainfall of the country ranges from 500 to 2800 mm with high variation in temperature >30$^{o}$C and < 10$^{o}$C (Demissew and Nordal, 2010). Such varied ecological conditions enabled Ethiopia to inhabit unique vegetation resources, each with its own characteristic flora and fauna (Tewolde, 1991).

The vegetation resources of Ethiopia are classified into 12 different types based on the altitudinal gradients in which they occurred (Friis et al., 2010). Of which, six of them could be considered as forests including the Dry Evergreen Montane forest, Moist Montane forest, Lowland Dry Evergreen forest, *Combretum-Terminalia* woodland, *Acacia-Commiphora* woodland, and Bamboo forests. The flora in each of these forests is heterogeneous, where 12% of the vascular plants are endemic (Anonymous 1997). The forest resources and their distribution are briefly presented below (Table 1) (Asefa et al., 2020; Friis, 1992; Friis et al., 2010; NBSAP 2005, Sebsebe Demissew et al. 2004; Wubet et al., 2003; Gebrehiwot and Hundera, 2014). The rapid increase of the population in Ethiopia coupled with the ever-increasing demand for forest products as well as the expansion of land for crops and grazing is among the major causes of the ongoing deforestation in the natural forest systems of the country (Lemenih and Kassa 2014). The change in natural forest cover is estimated to be between 150,000 and 200,000 ha year$^{-1}$ (Zewdie et al. 2009). A recent report indicated an average forest loss, which was estimated at 91,000 ha year$^{-1}$ (MEFCC 2018). Thus, the creation of plantations of fast-growing trees has become a major forestry practice, thereby reducing pressure on natural forest resources (Bekele, 2011; Zewdie et al., 2009). This strategy has led to a rapid expansion in the number of exotic tree species, and more than 1,000,000 ha of land have been planted with exotic species in the recent past decades (Bekele, 2011; Tesfaye et al., 2020). Most of these plantations were established as community forests and have considerable potentials for the sustainable production of high-value timber and non-timber forest products (NTFPs) (Bekele and Lemenih, 2008), including wild mushrooms (Dejene et al., 2017a).

Table 1: Major Forest types in Ethiopia classified based on altitude in which they occur: their distribution and dominant species.

| Forest type | Altitude (masl) | Distribution | Major tree species |
|---|---|---|---|
| Dry evergreen montane forest | 1,500 to 2,700 | Central, South-eastern, Eastern, Northern and Southern highlands | *Juniperus procera, Afrocarpus falcatus, Prunus africana, Olea* sps., *Myrsine africana, Calpurnia aurea* |
| Moist evergreen montane forest | 1,500 to 2,600 | South-western parts and Southern slopes of the Bale | *Pouteria adolfi-friederci, Pouteria altissima, Croton macrostachyus* |
| Lowland dry evergreen forest | 450 to 600 | South-western Baro lowlands of Gambella | *Acalpha neptunica, Alstonia boonei, Celtis gomphophylla, Mimulopsis solmsii* |
| *Combretum-Terminalia* woodlands | 500 to 1,900 | North-western, western and South-western | *Acacia spp., Commiphora africana, Commiphora myrrha, Boswellia* sps., *Moringa* sps. |
| *Acacia-Commiphora* | 900 to1,900 | Southern and central Rift Valley, and Eastern and South-eastern lowland | *Acacia sp., Balanites aegyptiaca, Commiphora* sps., *Boswellia spp., Moringa* sps. |
| Bamboo | 2,000 to 4,000 | Southern and central Rift Valley, and Eastern and South-eastern lowland | *Arundinaria alpine and Oxaytenanthera abyssinica* |

## 1.2. Non-timber forest products in Ethiopia and their importance

NTFPs in Ethiopia cover a wide range of products and are most extensively used to supplement diet and household income, notably during particular seasons in the year, and to help meet medicinal needs (Teketaye and Limenih, 2005; Eshete et al., 2005). They are largely important for subsistence and economic buffer in hard times (Dejene et al., 2020). These products also contribute to the improvement of the livelihoods of rural communities by providing employment opportunities and foreign exchange earnings of the country (Eshete et al., 2005; Kassa et al., 2009; Shummi, 2009). The significant value and importance of NTFPs is felt more in dryland areas where few alternatives of resources exist for supporting the livelihoods of local communities because of difficult environmental conditions (Teketaye and Limenih, 2005; Eshete et al., 2005). In Ethiopia, non-farm income represents an important element in the livelihoods of the poor. In several areas, where the population density and depletion of natural resources are high, agriculture cannot possibly remain the only source of income (Teketaye and Limenih, 2005). Observations show that, in many areas, crop production is no longer the main source of income for poor rural households (Resal, 2000). Therefore, it is essential for rural households to look for non-farm activities like productive exploitation of NTFPs to supplement agricultural production.

NTFPs provide a very good opportunity for sustainable forest management and community development in the last two decades (Shackleton et al., 2007). There has been increasing recognition of their contribution to household economies and food security, to some national economies and particularly to environmental objectives, including the conservation of biological diversity (Arnold and Perez, 2001). The role of NTFPs to the livelihoods of rural communities is likely to continue as long as the resources are exploited on a sustainable basis (da Silva Falcao et al., 2021), as they were using these resources for centuries (Jimoh et al., 2013; Mujawamariya and Karimov 2014). On the other hand, exploitation of NTFPs for commercial purposes contributes to local economies, hence contributing to community development (Saha and Sundriyal, 2012). The only drawback to this scenario is that commercialization could also result in overexploitation and depletion of the resources (Stanley et al., 2012). Therefore, a balance has to be stricken between resource sustainability and benefits of exploitation of products, particularly for the export market.

In general, the overall cultural, socio-economic, environmental, ecological and biodiversity importance of NTFP has been overlooked although NTFPs play a significant role in the daily life and well being of millions of people in many tropical countries including Ethiopia. Thus, historically, early forestry work tended to ignore this fact and it was mainly focused on managing forests for the continued supply of timber (Dejene et al., 2020). In addition, by complementing wood-based management, they offer a basis for managing forests in a more sustainable way, thereby supporting biodiversity conservation (Friis et al., 2005; Desalegn and Tadesse, 2004). Increased demand has not led to improved management including domestication, and a substantial proportion of products are collected from the wild, hence resource depletion is a major problem (FAO, 2003). Further, Ethiopian has not been able to take advantage of its wealth of raw material and traditional knowledge and investing on processing—undermining opportunities for employment and income generation from the NTFPs productions. Although NTFPs play a major role in the rural economy of Ethiopia, information on their overall contribution is patchy and incomplete at best, except for a few species and products of commercial importance (Eshete et al., 2005; FAO, 2003). The lack of systematic efforts to conserve and manage resources is a major concern and it is in only a few cases that efforts have been made to cultivate species that yield NTFPs (Kassa et al., 2009).

## 1.3. Major non-timber forest products in Ethiopia

Ethiopian natural forests and woodlands hold diverse commercially important NTFPs. The most commercially attractive NTFPs are gum and incense, honey, forest coffee, beeswax, and bamboo (Desalegn and Tadesse, 2004). There is considerable room to improve and enhance the economic importance of the NTFPs through improving their production, quality assurance, and value additions. The production and utilization of the various NTFPs in the country can be enhanced by properly surveying, mapping, and understanding the resource base and their potentials for commercial utilization. Also, they can be optimized by improving their utilization through modernization, improving extension services and introducing production protection standards and commercialization. Finally, the expansion of the resource base through domestication and development of their value chains by cultivating business association (producer and traders associations' e.g. providing credit), supporting value-added processing, and increasing private sector investment. Four NTFPs are targeted by the country's National Forest Sector Development Program (NFSDP): gum and resin, honey and beeswax, and forest coffee (NFSDP 2018).

### 1.3.1. Gum and resin

Of the total vegetation types of Ethiopia, seven are found in the dry areas of the country. The two dominant dry forest types in the dryland areas are the *Combretum–Terminallia* and the *Acacia–Commiphora* woodlands. The *Combretum–Terminalia* woodland and wooded grassland vegetation that is located in the lowland dry areas occur in large parts of the lowland of northwestern and western parts (Gondar, Gojam Wellega, Illubabor) and southwestern region (Gamo Gofa, Kefa) of the country. This *Combretum–Terminalia* woodland vegetation is often dominated by a combination of *Boswellia papyrifera*, *Anogeissues leiocarpa*, *Terminalia brownii*, *Tamarindus indica*, *Combretum collinum*, *Balanites aegyptiaca*, *Commiphora africana*, *Erythrina abyssinica*, and *Stereospermum kunthianum*. The species composition varies most strongly with altitude, ranging from 500 masl to 1.900 m a.s.l. (Awas et al.  2001, Awas 2007).

This vegetation provides livelihood diversification, wood, and food security, animal feed, human health care, and environmental conservation to rural and urban households (Lemenih and Teketay 2003a).

### 1.3.2. Wild edibles and fungi

Wild edible plants are among the groups of NTFPs that play a prominent role in uplifting the socio-economy of human beings, particularly in tribal and rural areas for thousands of years (Maikhuri et al. 2004; Dhayani et al. 2007). In Ethiopia, there are about 370 indigenous edible plants (belonging to 70 different families) out of which 182 species (40 families) are shrubs/trees with edible fruits/seeds. Of these, 203 wild and semi-wild plant species are documented (Asfaw and Tadesse 2001). Edible plants of Ethiopia are estimated to be about 8% of the higher plant species, where about 25% of these are cultivated as food crops and the remaining categorized as wild, semi-wild, or naturalized (Asfaw and Tadesse 2001). While, other literature identified, reviewed, and documented more than 90 tree species as wild food tree species in Ethiopia (Teketay and Eshete 2004). The major wild edible plants in Ethiopia include *Adansonia digitata*, *Annona senegalensis*, *Balanites aegyptiaca*, *Berchemia discolor*, *Carissa spinarum*, *Clausena anisata*, *Cordia africana*, *Dovyalis abyssinica*, *Ficus sur*, *Ficus vasta*, *Flacourtia indica*, *Grewia ferruginea*, *Mimusops kummel*, *Phoenix reclinata*, *Protea gaguedi*, *Rhus vulgaris*, *Rosa abyssinica*, *Rubus apetalus*, *Syzygium guineense*, *Syzygium guineense*, *Tamarindus indica*, *Ximenia americana*, *Ziziphus spina-christi*, and *Zizyphus mucronata* (Balemie and Kibebew, 2006; Addis, 2009; Teklehaymanot and Giday, 2010; Fantahun and Hager, 2010; Teketay and Eshete 2004, Teketay et al., 2010, Lulekal et al., 2011).

Apart from the trees and shrubs, important edible fungi (N> 20) were reported from forests in Ethiopia (Dejene et al., 2017a). In various cultures, wild edible plants can serve as an important source of food (Boa 2004), medicine (Ferreira et al., 2010), enzymes, and various industrial compounds (Gryzenhout et al., 2010). They also serve as important components of food and recipes for traditional foods and recipes (Marconi et al., 2018; Durazzo et al., 2017). Nutritionally, wild edible plants including mushroom and wild fruits are an important source of proteins, vitamins, fats, carbohydrates, amino acids, and minerals (Bano et al., 1993; Mattila et al., 2001), i.e., they are also good alternative or substitute for animal protein (Mattila et al., 2001; Kakon et al., 2012; Dejene et al., 2020). Furthermore, economically, some valuable edible species are important because their fruit, vegetable, oil, etc., has a wide range of domestic and industrial uses (Gunasena, H.P.; Hughes 2000). For example, in Ethiopia, the fruit of *Tamarindus* species is used for food and medicinal purposes by local communities (Girmay 2020). In addition, rural people sell Tamarind fruit in local markets to generate income to supplement the household economy in lowland areas of the country (Mengistu and Hager 2008). Similarly, in the highland part of the country, different edible fruit trees such as *Syzygium guineense* (Willd.) DC, is also available in the market by the local community to generate income to supplement their household economy (Mengistu and Hager 2008).

## 1.4. The need for the study

In Ethiopia, mushrooms are wild edible resources, particularly in the Southern and Southwestern parts of the country (Asfaw and Tadesse 2001; Dejene et al., 2017b; Lulekal et al., 2011). Despite poor scientific knowledge, wild mushroom utilization is a common traditional practice among different ethnic groups in Ethiopia (Semwal et al., 2014, Tuno 2001). Mushrooms, along with other wild edible resources, are used as a coping food during periods of food shortage in localities where they are used as food (Dejene et al., 2017b, Awas et al., 2010). In some local markets, mushrooms are sold by local people to provide some income to supplement the household economy (Abate 2014). However, there are few ethnomycological reports and the available reports are also scanty and contain only basic information about the existence and use of mushrooms at some community levels in the country (Tuno 2001, Abate 2014, Muleta et al., 2013). However, due to a continuing exodus of people from the countryside, local communities are gradually losing an important part of their traditional knowledge, particularly the ethnomycological aspects of mushrooms (Dejene et al., 2020; Härkönen et al., 2015; Kamalebo et al., 2018). Thus, there is a genuine need to record and document local traditional knowledge and perceptions about useful wild mushrooms in the country. Furthermore, due to their economic value, efforts are needed to integrate wild mushroom species as mainstream NTFPs in Ethiopia to ensure their conservation and enhance their value as a source of nutrition to improve human welfare. Thus, assessing the various uses of wild mushrooms by local people is a key to the better valorization of services provided by wild useful fungi (Beza 2017). This would also enable us to better elaborate participative management and conservation plans for the forest resources in the country.

Despite the benefits that can be derived from the management and proper conservation of wild edible fruit trees, the progressive forest land-use change, particularly the conversion of forest lands to agricultural fields of crops in dryland areas of Ethiopia, has imposed pressure on them (Dejene et al., 2020; Girmay et al., 2020). This land-use change has had a serious impact on the wild edible trees particularly on the Tamarind tree population because the tree species depend on natural regeneration (Lulekal et al., 2011). Furthermore, the available information generally lacks adequate quantitative analysis for the development of economic opportunities based on local resources such as Tamarind trees as an alternative to the excessive import of exotic products (Fandohan et al., 2011). Although some studies have been undertaken to investigate the fruit, morphological characteristics, and use of Tamarind in different localities in Ethiopia (Girmay et al., 2020; Lulekal et al., 2011), the species is still inadequately characterized. Thus, studying how land use influences the population structure of Tamarind trees might help us to develop effective conservation strategies in accordance with the needs of the local population. In particular, a better understanding of Tamarind dimensional structure could be used as the basis for strong management decisions if this is combined with information about the species spatial distribution (Sundriyal and Sundriyal 2001), patterns of use, and harvesting (Paul et al., 2019; Duchok et al., 2005). Furthermore, given the contribution of Tamarind fruit to the livelihoods of rural people in Ethiopia, an evaluation of potential yields and important tree parameters that influence fruit production are imperative to enable further improvement and management of this tree.

On the other hand, dry forests can produce a range of NTFPs, even to a certain extent in combination with forest-compatible uses such as livestock grazing (Dejene et al., 2013). Thus, managing of the dry forests is currently considered critical for their continued viability as a source of crucial resources in dryland areas of Ethiopia. Based on these considerations, the National Forests Sector Development Program of Ethiopia (NFSDPE) has devised a strategy to conserve and develop the country's forest resources, with the aim of increasing the proportion of Ethiopia covered by forest from 15% to 20% by 2028 (MEFCC 2018). This strategy also aims to enhance the production and utilization of various NTFPs, such as gum and resin, by undertaking surveying, mapping, and investigations of the resource base and assessing their potential for commercial utilization in dryland areas (MEFCC 2018). Thus, to conserve, manage and use the existing *Senegalese senegal* stands in the South Omo Zone, it is crucial to understand the current population structure, density, and natural regeneration of this species. Furthermore, the conservation and sustained management of *S. senegal* stands appears to depend largely on the benefits that rural households receive from this species. Thus, an estimation of gum arabic yield potential and an understanding of important factors that influence gum production is imperative. Such information could be used to devise management strategies (Sundriyal and Sundriyal 2004) and subsequently provide adequate information for setting appropriate harvest levels based on the status of the species (Duchok and Kent 2005; Paul et al., 2019). In general, the information gathered in this research could help to safeguard the longevity and the proliferation of valuable NTFP-producing tree species and their products in the country, as well as the livelihoods supported by these resources, both in the study area and country-wide.

## 1.5. Scope of the study

This thesis work is a systematic attempt focused on describing the ethnomycological aspects of three ethnic groups from two geographical regions and on evaluating major NTFPs from the dryland areas of Ethiopia. The field studies were based upon socioeconomic, vegetation and production inventories. Thus, we analyzed fruit and gum arabic yield from *Tamarindus indica* and *Senegalia senegal* trees respectively, to describe their potential production. The yield evaluation needs to be further completed with a more years sampling to describe the production aspects in detail, and even including an analysis of other complementary factors affecting the production. However, our pioneering reached findings are an indicator for the high potential yields and their significant contribution to the rural communities. The information generated can also serve as a basic document for further ethnomycological studies and NTFPs yields in the dryland region of the country. The obtained results of this doctoral thesis provide baseline information in broadening the sustainable management and conservation objectives for underutilized NTFPs use from the dryland forests of the country.

# Objectives

# 2. Objectives of the thesis

## 2.1. General objective

The overall aim of this thesis was to generate baseline information to enhance the conservation, promotion and sustainable utilization of the underutilized and threatened NTFPs in Ethiopia, taking into account local communities as the main actors. Thus, this general goal was assessed through the following specific objectives.

## 2.2. Specific objectives

- To assess and document ethnomycological knowledge related to wild mushroom species of three ethnic groups from three different geographical areas in Ethiopia.

- To assess the population patterns and dendrometric characteristics of *Tamarindus indica* trees growing on farmland- and bushland-use types in the lowland parts of Ethiopia.

- To evaluate the stand status and potential yield of gum arabic from *Senegalia senegal* and to understand important factors that influence the gum production from this species in Ethiopia.

# *Methodology*

# 3. Material and methods

## 3.1. Description of the study area

The study consisted of two parts including the vegetation survey and socioeconomic study. The vegetation survey was conducted in Bena Tsemay and Dello Mena Districts for the *Senegalia senegal* and *Tamarinuds indica* respectively. On the other hand, the socio-economic survey was conducted in Wondo Genet, Banja, and Fogera Districts in Sidama and Amhara regional states respectively (Figure 2).

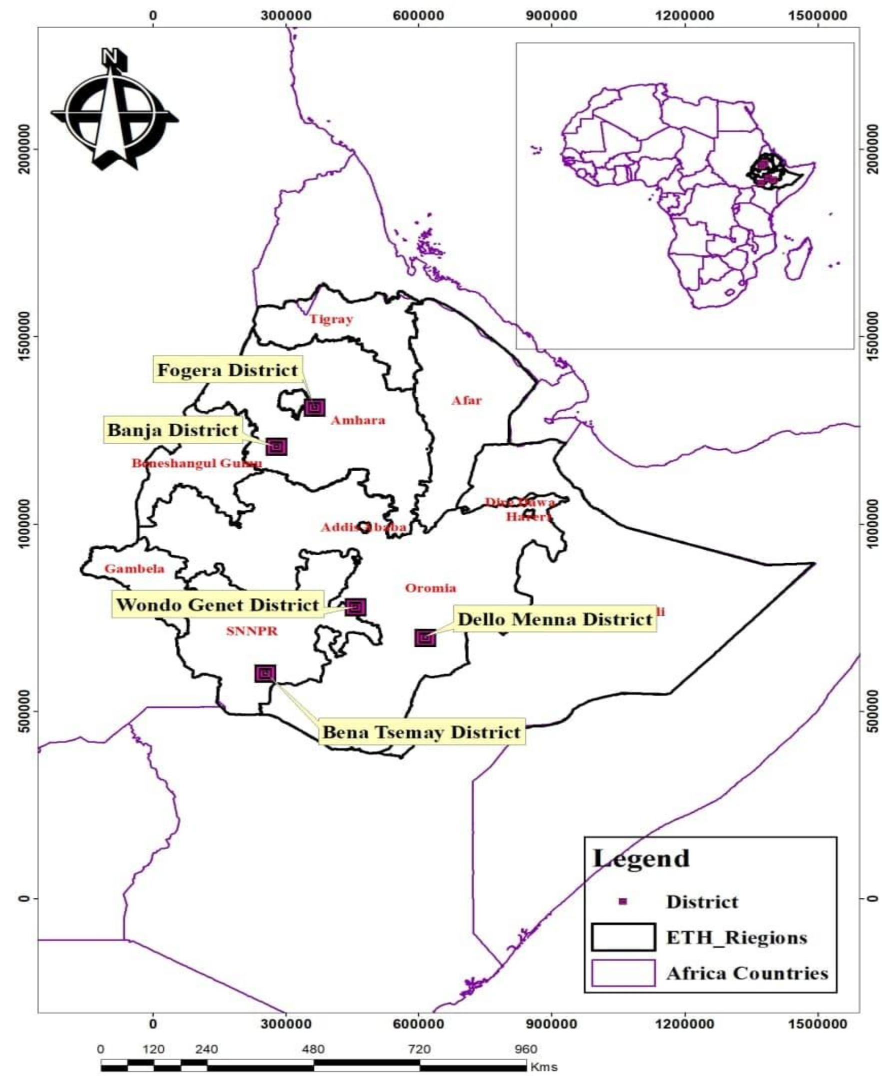


**Figure 2:** Map of Ethiopia showing the location of the study districts.

The socio-economic survey was conducted in the Amhara and the Southern Nations, Nationalities, and Peoples' Region (SNNPR) of Ethiopia where more than half of the ethnic groups of Ethiopia reside and from which three ethnic groups were selected: namely, the Amhara in the Fogera District, the Agew in the Banja District and the Sidama in the Wondo Genet District (Figure 2). These three ethnic groups had been identified in this study with the assumption that they are having good knowledge of the identification, variability, and use of locally available NTFPs. The Amhara and Agew ethnic groups occupy the center of the northern highlands of the Amhara region. They live in the same agroecological zone and share the same cultures and languages. They both are sedentary farmers who practice mixed agriculture, including crop production and livestock rearing. The crop varieties grown locally in these Districts include teff, sorghum, maize, finger millet, and beans. Similarly, the Sidama ethnic group is one of the largest ethnic groups in the southern highlands. The population density in Wondo Genet is higher than that of Fogera or Banja, with about seven inhabitants per km$^2$. The majority of the Sidama practice mixed agriculture, integrating cash crops, such as khat (*Catha edulis*) sugar cane, and Ensete, with livestock production, including fishing from the nearby lake. On the other hand, the three ethnic groups from the Amhara Region occupy the center of the northern highlands of the Amhara region. They live in the same agroecological zone and share the same cultures and languages. They both are sedentary farmers who practice mixed agriculture, including crop production and livestock rearing. The crop varieties grown locally in these Districts include teff, sorghum, maize, finger millet.

Figure 3: Field data collection in the study area: a socioeconomic survey (A) and Vegetation survey (B). (Photo credit: Wubalem 2020).

The vegetation survey was conducted in Bena Tsemay and Dello Menna District (Figure 2). The Bena Tsemay district is found in the South Omo administrative zone of the SNNPR. The district is located between 5.11°– 5.70°N and 36.20°– 37.04°E (Assefa and Abebe 2010), with average temperatures ranging from 10.1 °C to 27.5 °C and a mean annual rainfall ranging from 400 to 1600 mm. The study area is characterized by bimodal rainfall: the first rainy season occurs from mid-March to the end of April, which is important for crop production; a second short rainy season occurs from mid-October to the beginning of November, which is important for pasture production. The study area is 500 –1500 m above sea level (masl) (Assefa and Abebe 2010). The dominant vegetation types are mixed, the *Combretum–Terminalia,* and *Acacia–Commiphora* woodlands, which are used as rangelands and common property resources of the whole community (Soromessa et al., 2004). On the other hand, Dello Menna district (between 5°53'N and 6°27'N and between 39°15'E and 40°38'E) found in the Bale zone of Oromia regional state, Southeastern Ethiopia. Dello Menna is 800 to 2000 m a.s.l and characterized by bimodal rainfall. The main rainy season occurs from early March until the end of June, followed by a shorter rainy season from late September until the end of November. The mean annual rainfall is 986 mm, and the mean annual temperature is 22.3 °C. Dello Menna has a plain topography with a few areas of rugged and mountainous terrain. Nitisol is the dominant soil type in this area (Ermias et al., 2008), ranging from a reddish-brown clay toward the higher altitudes and tending to form a reddish-orange sandy soil toward the lower altitudes. Rocky outcrops are prevalent along streams and steeply sloping hills. The inhabitants of the area practice a mixed farming system involving livestock and subsistence agriculture, which is the main livelihood of the rural community (Senbeta 2006). Coffee, bananas, and papayas are the main perennial cash crops. Teff, sorghum, and maize are the main annual crops cultivated by farmers.

## 3.2. Data collection

### 3.2.1. Ethnomycological study

This ethnomycology study presents three case studies as a type of socioeconomic research, each with various forms of socioeconomic data which were collected between January and August 2019. The data were collected from the primary data sources that involved the key informant interviews, focus group discussions, and household interview methods. To select key informants, a snowball method was used in which one key informant was contacted with the assistance of local administrators and community elders. Focus group discussions assessed the perception of 300 households on wild mushrooms, their knowledge of ecological niches and phenology/calendar use, as well as their opinion regarding resource degradation.

Household interviews were conducted using a face-to-face semi-structured questionnaire interview. Information regarding the gathering, preparation, status/abundance, etc. of wild mushroom species and their marketability was also collected. The collected information was qualitatively interpreted and narrated in the Results and Discussion. Details of the methods used followed Mekonnen et al. (2018) and are described in study one.

### 3.2.2. Vegetation status study

Woody vegetation characteristics, such as species composition, density, and size structure of the *Tamarindus indica*, were measured by placing transects across the two major land-use types in the study district, namely farmland and bushlands in 2019. For this purpose, we used the point-centered quarter (PCQ) method, a “plot-less” sampling technique, at points along transects across the sampled areas (Kevin 2015). The transect direction was determined randomly by selecting a bearing from the center of each land-use system, with another transect perpendicular to the first transect (i.e. two cross-cutting transects at 90 degrees). A series of points 100 m apart were systematically located along each transect. A total of 25 and 29 sampling points were used for farmland and bushland-use types, respectively. At every sampling point, four quadrants (90 degrees) were created using the transect line and a line perpendicular to it. The measurement and recording of species in each quadrant were carried out in two stages. Firstly, the *T. indica* that was closest to the sampling point in each of the four quadrants was selected (all sizes were sampled, i.e., seedlings, and mature trees) and then its distance from the central point was recorded. Tree diameters above the basal swell were also measured. Secondly, any woody plant species closest to the sampling point within each of the four quadrants were selected, and the distance from the central point and the tree diameter was recorded.

For *Senegalia senegal,* the vegetation data were collected in sample quadrants placed along transect lines, which were laid out systematically (Didita et al., 2010). A total of 45 plots, 20 × 20 m in area, were laid out along 10 transect lines based on the concept of minimal area (Kent 1992). Plots were laid out every 500 m along transect lines, which were laid 400 m apart. All woody plant species, including trees and shrubs, were recorded in the 20 m × 20 m quadrants, whereas seedlings were counted in 1 m × 1 m subplots that were subjectively placed within the main plots (Wale et al., 2012; Dejene et al., 2014). All plant species were counted at an individual level within each main plot and subplot. Height and diameter at breast height (DBH) measurements were recorded for any woody plant species with a height ≥ 1.5 m and a

DBH ≥ 2 cm. Individual plants with a height < 1.5 m and a DBH < 2 cm were counted (Eshete and Teketay, 2005). Height and DBH measurements were obtained using a clinometer and a diameter tape, respectively. Plants < 1.5 m in height were measured using calibrated sticks (Eshete and Teketay, 2005).

In both cases, every plant species encountered in each plot was recorded using their scientific name. Vernacular names were also recorded whenever possible. For those species that were difficult to identify in the field, plant specimens were collected, pressed, and then taken to the Ethiopian Environment and Forestry Research Institute for taxonomic identification. Published volumes of the Flora of Ethiopia and Eritrea (Hedberg and Edwards 1989; Teketay and Granström 1995) were used to identify plant specimens.

### 3.2.3. Yield estimation study

The productivity of each Tamarind tree in terms of fruit yield was measured using the harvesting method described by Sundriyal and Sundriyal (2004). In total, 27 individual fruit-producing Tamarind trees in each land-use type were randomly selected (Cunningham 2001). The total number of branches and the number of fruit-bearing branches were also recorded during the fruit-harvesting period, as described by Cunningham (Cunningham 2001). To obtain an accurate record of the number of fruits produced per tree, Tamarind fruit were counted when fully matured (Agwu et al., 2020) (i.e., when pods had turned from green to brown) but before the fruit had fallen or been eaten by wild animals. The number of fruits on each terminal branch was determined by either standing on the ground to count fruit hanging down below the canopy, or by climbing the tree to count those in the canopy, or by using a ladder to count those at the top of the crown. Fruit numbers and their weight were recorded for each terminal branch separately and summed for each branch and then the total for each tree was obtained by summation. In addition, tree dendrometric variables such as height, diameter at breast height (DBH), crown diameter, and the number of branches were recorded (Miller and Dietz 2004). Crown surface area, crown volume, and crown depth were estimated using the measurements obtained for the other dendrometric variables. The DBH was measured using a diameter tape and total height was measured using a Suunto Clinometer. The crown diameter was measured using a cross-method, where the length of the longest spread from edge to edge across the crown and the longest spread perpendicular to the first cross-section through the central mass of the crown were measured. The crown diameter is the average of these two lengths. The number of branches on each tree was also counted in the field.

Gum production from *S. senegal* was evaluated on a per tree basis using the harvesting method (Alemu et al., 2013; Saha and Sundriyal 2010). Thirty-six individual *S. senegal* gum-producing trees growing in the study area were randomly selected. The selected trees had an almost uniform diameter. They were tagged and tapped with a "sunki" axe to yield strips of relatively similar depth, width, and length. The gum was harvested from each tree in January and February. The gum yield from each harvest was collected in a separate labeled paper bag and weighed using a high-precision balance after drying at room temperature. The total yield data for each tree was obtained by summation.

## 3.3. Data analysis

### 3.3.1. Ethnomycological study

Descriptive statistics were used to present the basic information obtained from the questionnaires. All analyses were conducted based on the number of responses from the informants. A final list of edible wild mushroom species used by respondents was compiled from the questionnaires and field collection data. All fungi were identified at the genus and species level whenever possible with the aid of several keys (Antonín 2007; Hama et al., 2010; Heinemann 1996; Morris 1969; Rammeloo and Walleyn 1993; Ryvarden et al., 1994; Singer and Marasmius 1965). A Kruskal–Wallis test was performed to identify the major causes of wild mushroom degradation. Data were analyzed using STATISTICA '08 edition software (StatSoft Inc., 1984–2008, Maastricht, the Netherlands). There are many theoretical perspectives regarding food choice decisions, but each offers partial insights and makes limiting assumptions (Gujarati 1992). We used a food choice model that was developed based on constructionist social definition perspectives to examine the broadest scope of factors relevant to how individuals constructed their food choices. The model included components of the life course, personal food systems, and influences (Table 2 of study one).

### 3.3.2. Vegetation and yield studies

To assess the impact of land use on the Tamarind tree species, we compared variables relating to population structure, dendrometric characteristics, and fruit yield. Differences between the farmland and bushland use types for the different variables were evaluated using a one-way analysis of variance (ANOVA). The relationship between fruit yield and individual tree attributes was determined through the multinomial classification model approach. The models were fitted to the responses to predict the probabilities of the different possible outcomes of fruit yield categories (Umaña-Hermosilla et al., 2020). Data were analyzed using Statistical Package for Social Sciences (SPSS) version 23.

The population structure of Tamarind trees in both land-use types was assessed by assessing size class diameters using tree density data collected from PCQ (Kevin 2015; Beasom and Haucke 1995). Five diameter classes were used in this assessment: seedlings (recently regenerated), 1 to 10 cm; 11 to 20 cm; 21 to 30 cm; and >30 cm. The crown depth is a parameter used to calculate the crown volume and surface area of individual trees by subtracting the height to the lower side of the crown from tree height. The detail in the determination of total distances between trees and sampling points; the average distance of the sampled tree from the point; the formulas to determine the absolute and of all tree species (trees per ha) and relative density Tamarind could be found in the study two.

Figure 4: *Tamarindus indica* tree and its fruits in farmlands of the study area.

The population structure of *S. senegal* was shown using frequency histograms to depict the diameter classes and the number of seedlings (Eshete and Teketay 2005). All individuals of each species encountered in the quadrants were grouped based on their diameter into 5-cm diameter classes (Tilahun 2015; Ogbazghi et al., 2006). Frequency was determined based on the number of plots in which the species was recorded (Coughenour et al., 2015). Density was calculated based on the number of individuals of each species per unit of area (Eshete and Teketay 2005). Gum yield (kg per hectare and year) was calculated by multiplying the mean stem density per plot with the mean yield from previous studies (Dejene et al., 2014; Ogbazghi et al., 2006). The relationship between gum yield of *S. senegal* and individual tree attributes was determined through linear regression, where the power of regression equations was seen by their R-values. Coefficients of each equation were used to estimate the gum yield of individual trees. Data were analyzed using R software (Team 2020) the detail is in study three.

Figure 5: *Senegalia senegal* tree and its exude of the gum arabic.


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# *Results*

# 4. Results

## 4.1. Ethnomycological study

The ethnomycological survey of the three ethnic groups indicated that about 24 fungal species are known to be edible in the study areas. These edible mushrooms were well recognized by the local people when shown photographic images of these species. The families with the greatest numbers of edible species identified were the Agaricaceae and Psathyrellaceae. These two families represented 66.67% of the identified edible wild mushroom species in the study forests, whereas the remaining 33.33% of families were represented by only a single species. The Amhara and Agew ethnic group appeared to have limited ethnotaxa knowledge of the wild mushroom species, while the Sidama ethnic group was found to be mycophiles and to have a well-developed ethnotaxa for wild mushrooms. Some of the names given by the Sidama groups are associated with attributes of the mushroom species. For example, 'Meine' is a name given to a highly valued species that are good to eat due to its taste but scarce due to high levels of collection.

Six different habitat types were distinguished by respondents for mushroom collection. However, the home garden and swampy areas are far less relevant for the Amhara and Agew ethnic groups than other habitats. Compared with Sidama respondents, a significantly greater proportion of respondents belonging to the Amhara and Agew ethnic groups considered the natural forest to be the main mushroom habitat. By contrast, a significantly greater proportion of Sidama respondents considered grazing areas to be a mushroom habitat compared with the Amhara and Agew respondents. However, the proportion of Sidama and Agew respondents that considered plantations and agricultural lands to be habitats for wild mushroom species was not significantly different.

The household interview revealed that the Sidama ethnic group collects wild mushroom species for food (93%) and medicinal (7%) purposes. About 63% of the respondents indicated that they usually collect wild mushrooms, 25% indicated that they occasionally collect wild mushroom species, and 12% did not collect mushrooms. The Sidama collect fungal species that have different nutritional modes. Saprotrophic fungi are preferred as food (90%) compared with other fungal types whereas *Ganoderma*, *Calvatia,* and *Lycoperdon* are the three most commonly gathered genera for medicinal purposes. When dried, the spores of these mushroom species can be spread on the skin to heal wounds and skin disease. In all three ethnic group cases, wild mushroom species develop and are collected during the short (peak in March) and long (peak in July) rainy seasons, suggesting the importance of rainfall patterns in fungal phenology.

## 4.2. Vegetation status and yield studies

A total of 16 woody tree species belonging to nine families and 12 genera were recorded in association with *Tamarindus indica* in Dello Menna district (Table 1 of study two). In addition to *T. indica*, *Dobera glabra* was also identified on farmland as an edible fruit tree that was utilized by local communities in the study area. Analysis of the *T. indica* population revealed that a significantly greater number of mature Tamarind trees were recorded in bushland than on farmland ($F = 10.59$, $p = 0.01$; Figure 2B; Table 1 of study two). However, a significantly greater number of Tamarind trees with a DBH of >30 cm ($F = 1.69$, $p = 0.046$) and more regeneration ($F = 7.21$, $p = 0.021$) was observed on farmland than in bushland. The average DBH of trees on farmland was 58.78 ± 23.71 cm and seedling density was 15.81 ± 2.04 seedlings per ha (Figure 2B of study two). However, no Tamarind trees in the 1–10 cm, 11–20 cm, and 21–30 cm diameter classes were recorded on farmland (Figure 2B of study two). There was no significant difference in Tamarind tree height ($p > 0.05$) between the two land-use types. The total population status of *T. indica* trees for the two land-use types is shown in Figure 2B of Study two. Similarly, there was a significant difference in Tamarind fruit yield and dendrometric variables between the two land-use types (Table 2 of study two). Estimated variables such as the number of fruits, fruit yield per tree, DBH, and crown diameter of Tamarind were significantly higher for trees on farmland than in bushland ($p < 0.05$) (Table 2 of study two). A greater number of fruits were obtained from trees on farmland than in bushland, with a mean value of 4343 on farmland, ranging from 1485 to 8569 fruit per Tamarind tree, and an estimated mean annual yield of 537.05 kg. The mean number of fruits from trees in bushland was 2537, ranging from 1500 to 3500 fruit per tree. The individual fruits' weight did not show significant differences ($p > 0.05$) between the two land-use types (Table 2 of study two). When correlating variables with Tamarind fruit yield, we found strong correlations between fruit yield and variables such as the number of fruit (0.94) and the number of branches (0.54) ($p < 0.01$; Figure 3A of study two) for trees growing in bushland. Furthermore, predictive models were selected for Tamarind fruit yield estimations in both land-use types. The parameters from each group such as tree size, crown dimensions, and tree branches were tested in different combinations to identify the best model that potentially included one tree parameter from each group and the detailed result of the model is provided in Table 4 of study two.

Thirty-two tree species belonging to 26 genera and 13 families were recorded in woodland in the study area (Table 1 of study three). *S. senegal* had the fourth-highest tree density (41 individual stems ha$^{-1}$), accounting for 7% of stems. Sixteen tree species, including seven species of Commiphora, were identified as sources of commercial gum and resin-producing trees. The total population of *S. senegal* and of all the trees recorded is shown in Figure 2A of study three. A comparison of diameter classes of the three most common gum- and resin-producing tree species shows that there was a significantly greater number of B. neglecta trees in the 2–7 cm diameter class than of *S. Senegal* ($p < 0.0001$) or C. africana ($p = 0.009$). In diameter classes with a DBH > 12 cm, the number of trees of each species did not differ significantly ($p > 0.05$). Among the five gum- and resin-producing tree species showing natural regeneration, *S. senegal* seedlings were the most abundant (35.15% of seedlings), followed by *Grewia bicolor* (22.65%) and *Commiphora edulis* (18.75%). Together, these two species accounted for approximately 75% of the natural regeneration of gum-and-resin-producing trees (study three).

The mean gum yield per tree for the harvests in January and February differed significantly ($F = 12.62$; $p = 0.001$), with a higher yield obtained in January. The mean stem density of *S. senegal* trees with a diameter of more than 2 cm was 41 stems ha$^{-1}$. Based on these findings, we estimate that a mean gum arabic yield of approximately 190 to 84,578 g ha$^{-1}$ year$^{-1}$ could be expected from two harvest seasons. A linear model of the dendrometric variables indicated that gum arabic yield per *S. senegal* tree could be predicted by diameter ($p < 0.05$) rather than by height. Regressing gum yield against the diameter and height yielded the equations in Figure 5 of Study three. The R2 value of the diameter indicated that the model fits the data well.

# Discussion

# 5. Discussion

## 5.1. Ethnomycological study

In this ethnomycological study, we included two regions with different ethnic compositions. In our study, the surveys revealed that the Sidama ethnic group are mycophiles and have a more extensive folk taxonomy for mushrooms than other ethnic groups (Bao 2004; Tibuhwa 2012; Ekandjo and Chimwamurombe 2012). In addition to their use as food, *Lycoperdon perlatum,* and *Calvatia rubroflava* were reported to be the most useful and important medicinal wild mushroom species because they play a key role in treating wounds and skin disease. *Laetiporus sulphureus* has also been reported as a common traditional medicine for lessening pain during childbirth in the Kaffa areas in the southern part of Ethiopia (Abate et al., 2014). Other studies have also reported that these mushrooms are used in traditional medicine to treat stress, pain, measles, and lung diseases (Kadhila-Muandingi 2010; Sun et al., 2006; Adhikari et al., 2005). The Amhara and the Agew have limited ethnomycological knowledge and do not eat mushrooms even though their parents or grandparents have consumed wild mushroom species in the past. The non-consumption of mushrooms will eventually represent a loss of mycological knowledge in these ethnic groups (Kamalebo et al., 2018). Only two of the species common to their locality have been assigned a folk taxonomy by these ethnic groups (Table 3 of study one) while the common name of the majority of wild mushroom species was reported to be Enguday or Yejibtila. Therefore, rigorous work is needed in Banja and Fogera to develop a folk taxonomy (Dejene et al., 2017a, c). However, this study did provide us with an opportunity to understand how different ethnic groups in Ethiopia use their ethnomycological knowledge.

In this study, communities, particularly the Sidama, are able to distinguish between wild mushroom species using their own traditional protocols. Broadly, they used morphological characters, smell, and habitat to identify edible mushrooms. These criteria are in line with (Dejene et al., 2017a; Tuno 2010). The oldest accounts of this practice among tribes in developing countries have been putatively reflected by different authors (Borah et al., 2018; Kinge et al., 2017; Ongoche and Otieno 2017). Besides these criteria, in rural areas of Ethiopia, the local people also use the presence or absence of a strong bad smell (Tuno 2010) to determine the edibility of mushrooms. Thus, it could be assumed that such traditional protocols are the product of ancient experimentations and possibly opportunistic discoveries by the indigenous people despite the confounded genealogy of their cultural uses (Ekandjo and Chimwamurombe 2012).

Common areas identified for the wild mushroom collection were natural forests, farmlands, grazing lands, home gardens, and swampy areas. Most of these ecological niches are quite similar to those reported by (Abate et al., 2014; Muleta and Woyessa 2013) in the south and southwestern parts of the country. Respondents also revealed that all mushrooms are collected during the rainy season (June to September) and used especially during food shortage periods. However, Dejene et al. (2017a) reported that the collection of some species, such as *Laetiporus* sp., could occur during the dry season (Tuno 2001; Muleta and Woyessa 2013). If communities are trained well, this culture of collecting wild mushroom species could be expanded to shift from subsistence use to income-generating small-scale business speculations through their commodification.

We have got determinant variables on wild mushroom consumption by the local communities in the three study districts, implying that any of the significant variables have a positive effect on wild mushroom use by the local people. For example, “taste experience” has a positive effect on wild mushroom use in the study area. This implies that those individuals who have tasted a wild mushroom species have a better awareness of its use than those that have not tasted the species. This experience helps to understand the local livelihood context, the sources and nature of risks, and the coping behavior of communities. This supports the findings of Lemenih et al. (2004) who indicated that household experience is a commonly applied strategy for coping with shocks and is instrumental in poverty reduction. Thus, a local communities’ experience of tasting a mushroom has implications for poverty reduction through emphasizing locally available sources of the mushroom, enabling rural households to diversify their food sources. The same applied to the other positive coefficient variables, implying that a unit addition to any one of them will have a positive implication for wild mushroom consumption.

We evaluated different threats that affect wild mushroom species based on the perceived causes for degradation. Many of the threats related to habitat degradation are affecting wild mushroom species in Ethiopia in general. Free grazing and agricultural land expansion were considered to be the main threats in this study. This might be because rapidly growing human and livestock populations are driving an ever-increasing demand for crop and grazing land, which is aggravating the degradation of habitats in Ethiopia (Lulekal et al., 2011; Giday et al., 2009; Lemenih and Kassa 2014). Such anthropogenic pressures are likely to also have an impact on useful known and unknown wild mushroom species, some of which could face extinction (Lemenih and Kassa 2014). Moreover, this loss also limits the benefits that can be obtained from wild mushroom components of forest resources as well as the ethnomycological knowledge of different ethnic groups associated with mushroom use. Thus, the sustainable management of Ethiopian forest systems is mandatory in order to play major roles in the conservation and development of wild edible and medicinal mushrooms that cannot be economically cultivated, require very specific habitats, and are exceptionally difficult to reproduce in nurseries or laboratories. Furthermore, the importance of fungal resources has recently been brought to the forefront due to their ecological and economic importance. There have been many efforts to record their diversity at local and regional scales. Thus, product diversification is a fundamental strategy to integrate a model of sustainable forest exploitation and reverse the degradation of wild mushroom species through promoting ecosystem services such as biodiversity conservation.

## 5.2. Vegetation status and yield studies

To sustainably use and conserve the forest, we need to identify the potential species present and analyze their stand status and production potential, including harvesting level (Saha and Sundriyal, 2012). In the second study, the vegetation survey revealed that a total of 16 woody tree species were associated with the two land-use types studied. Fabaceae was the most dominant family, which is similar to the findings of other studies in the same area (Getachew et al., 2008; Didita et al., 2010). This may imply that the environmental conditions in this area are more favorable for species belonging to this family than to other families (Didita et al., 2010). The analysis also confirmed that land use impacts woody vegetation, particularly the distribution of Tamarindus indica in the study area. The density of Tamarind trees was much higher in bushland than in farmland. However, large trees were predominantly growing on farmland, which supports previous findings by Djossa et al. (2008), who reported that trees growing on farmland were significantly larger but lower in density than in bushland. This might be because agricultural areas are still farmed in fairly traditional ways and, thus, the overall tree density is low because of regular cropping (Chivaura-Mususa et al., 2000). However, the condition of these old trees will likely have long-term consequences for the continuity of trees on farmlands, specifically Tamarind trees, and in the long run, may even lead to population collapse. Thus, the establishment of management plans to create stands that have a more balanced age structure and, thereby, ensure the continuity of the Tamarind population on farmland, is necessary for this study area.

*Dobera glabra* was found in association with *T. indica* on farmlands in the study area. We observed that farmers deliberately retain vital edible fruit trees on their farmlands.  Fruit trees found on farmland in the study area might provide ecological, social, and cultural services (Manning et al., 2006; Gruenewald et al., 2007; Garbach et al., 2012). Such trees could play a vital role in food security because their fruit is generally collected for subsistence use by local communities (Lulekal et al., 2011; Agúndez et al., 2016; Faye et al., 2011). They have also considerable importance in local and national economies. In spite of these, local consumption and commercialization on a small scale (Diallo et al., 2008).

In this study, the productivity of *T. indica* significantly varied between the two land-use types, with higher levels of productivity recorded for trees growing on farmland than in bushland. Although fruit yield varies seasonally, the number of fresh fruit and the yield per Tamarind tree on farmland was 42% and 64% higher, respectively, than that in bushland. Although the seasonal variation of the yield is usually related to the environmental conditions, the effect may vary with plant species (Fandohan et al., 2011). These results are consistent with the findings of other studies that wild edible trees on farms produce more fruit than unmanaged trees in woodlands (Okia et al., 2011; Shackleton and Shackleton 2006). Such significant differences in fruit yield under different land-use types might be attributable to differences in environmental variables, the level of tree management on farmland as well as the productivity of trees in terms of fruit weight and size (Anegbeh et al., 2003; Fandohan et al., 2011). Thus, in this study, the higher fruit yields from farmland compared with bushland implies that Tamarind trees could benefit from improved management on farms such as hoeing, weeding, and reduced competition with other trees (Kimondo et al., 2011). However, although Tamarind trees may tend to produce a large number of high-weight fruit under farmland conditions, the majority of the sampled trees produced between 2000 and 5000 fruit per tree. This may indicate that *T. indica* trees growing on farmland have undergone intentional selection owing to local communities removing less-productive trees from farms, suggesting that fruit yields could be further improved through deliberate selection of superior yielding trees from farmland types in the study area.

In order to increase the practical usefulness of the model and to avoid large errors in the estimation of Tamarind fruit yield, models with one dendrometric parameter predictor from each group were chosen. In this regard, the models holding the combination of DBH, crown diameter, crown volume, crown surface area, and the number of branches were used to predict Tamarind fruit production from the farmland-use type, while the parameters of the DBH, crown diameter and number of branches were used to develop models for bushland-use type. Similar types of studies have also concluded that the chosen tree parameters best predicted the fruit yield of Vitex trees under different land-use conditions (Kimondo et al., 2011), whereas other studies have suggested that DBH measurements better estimate fruit yields of

Baobab (Gebauer et al., 2016) and Vitex trees (Miller et al., 2004) using a linear regression model. However, the tree size, crown structure, and the number of branches of Tamarind trees are affected by environmental and geographical factors such as rainfall, temperature, latitude, and longitude, and soil conditions (Osorio et al., 2018; Ranaivoson et al., 2015), which directly affect the accuracy of the models when used for fruit estimation in other places than the study area. Thus, the use of a site-specific model may be recommendable for more accurate fruit yield estimations of Tamarind trees. Furthermore, in this study, the correlation of dendrometric parameters suggested that under enhanced management, Tamarind trees in both land-use types could achieve better yields and structure. However, since *T. indica* can be grown in a diverse dryland area of Ethiopia, a comprehensive study considering management and germplasm selection is required to validate the equation developed in this study.

The third study identified 42 vascular plant species, of which 16 species (38%) were gum- and resin-producing tree species, which were considered the most useful trees. The number of gum- and resin-producing species recorded in this study appears to be higher than that reported to date from other dryland agro-ecologic zones in Ethiopia. For example, only *Senegalia senegal* and *Vachellia seyal* were reported as gum- and resin-producing tree species in a survey of the central Rift valley woodlands of Ethiopia (Yebeyen 2006). Other studies of the northern part of Ethiopia have reported *Boswellia papyrifera*, *S. senegal*, *V. seyal*, and *Sterculia setigera* as the main sources of gum and resins (Eshete 2011). In general, our findings suggest that the South Omo Zone supports more gum- and resin-bearing species than other parts of the country and, hence, there is a greater opportunity for the commercialization of different NTFPs in the form of gum, resin, and myrrh (Worku et al., 2011; Lemenih and Kassa 2010). Apart from gum and resin-bearing tree species, we also found some important wild tree species with edible fruit, such as *Dobera glabra*, which could play a vital role in food security in dryland areas because this fruit is generally collected for subsistence use by local communities (Melaku et al., 2014). Consistent with other studies, the presence of these valuable tree species among the vegetation of the study area suggests that this forest resource could enhance the livelihoods of local communities through income generated from the various NTFPs (Dejene et al., 2013; Eshete and Teketay 2005).

Previous studies of gum production have involved stands of *S. senegal* trees with a diameter ≥ 4 cm (Alemu et al., 2013). In this study, we sampled trees with a diameter ≥ 2 cm because Yebeyen (2006) reported that these trees are considered to be sufficiently mature for gum production purposes. The average density of *S. senegal* trees with a diameter ≥ 2 cm was 41 stems ha$^{-1}$ (37% of *S. senegal* stems in the study woodland), which is lower than that reported in other areas of Ethiopia. For example, Yebeyen (2006) reported 12–209 *S. senegal* trees $ha^{-1}$ in the rift valley areas of Ethiopia. Similarly, Dejene et al. (2014) reported 211 trees $ha^{-1}$ in Abderafi district in northwest Ethiopia. The higher density of *S. senegal* in both these areas might be because the vegetation is dominated by *S. senegal* trees in these areas. In our study, *S. senegal* was mainly found in association with *Vachellia tortilis*, *Senegalia mellifera*, *Vachellia nilotica*, *C. edulis*, and *D. glabra*. Most of these species have a wide, dense crown that is umbrella-like and flat-topped (Azene et al., 1993). Tree dimensions and structures are of great importance in natural and managed forest ecosystems because they can influence the resource retention capacities of individual trees and, hence, affect their growth and survival (Schneider et al., 2020). Thus, trees with a dense umbrella-like crown, together with aspects such as the capacity of the forest soil to retain water or rainfall, might limit the number of individual plants per area that can grow under this type of tree and, hence, the overall composition of the vegetation in the ecosystem. Despite the comparatively low density of matured *S. senegal* trees in the study woodland, there is a sufficient number of *S. senegal* trees and associated gum- and resin-producing tree species to support the launch of a commercial gum arabic and resin-harvesting enterprise in the study area. In addition, the regeneration status of *S. senegal* is good compared with that of other species found in the study area, possibly reflecting the abundant seed production of *S. senegal* and their contribution of seeds to the soil seed bank (Senbeta and Teketay 2001). The thorny nature of *S. senegal* might also help seedlings to escape the browsing effects of cattle (Dejene et al., 2014), which might indicate that *S. senegal* trees are a sustainable resource in this study area.

The average gum arabic yield from tapped trees in this study was 2060 g $tree^{-1}$, with yields ranging from 266 g to 3948 g $trees^{-1}$ in a two-month period, indicating a high level of variation in gum yields among individual trees. Although the information on gum yield from different provinces is scarce, our findings agree with those of a similar study conducted in Ethiopia. Alemu et al. (2013) showed that gum yield from a managed plantation of *S. senegal* trees could provide on average 96 g per two months of harvesting. Furthermore, a study performed in the Abderafi area, where the woodland is dominated by *S. senegal* trees (211 stems $ha^{-1}$), estimated that 190 to 422 kg $ha^{-1}$ $year^{-1}$ of gum arabic could be harvested, which could be worth approximately $US 950 to 2110 $ha^{-1}$ $year^{-1}$ (Dejene et al., 2014). The yield estimated in this study is based on two harvests in January and February, which may be a more intensive period of tapping compared with those of other studies, which may have resulted in a lower annual gum yield per hectare in our study area compared with that of other studies. However, taking the overall average gum arabic yield of 2060 g per individual tree and dividing it by 16 tapping seasons, the overall average yield/tree/season would be 129 g per season. Therefore, the predicted yield that could be obtained from the *S. senegal* trees in our study is greater than that predicted by Dejene et al. (2014) and Alemu et al. (2013) for natural and plantation forests, respectively.

The relationship between gum yield per tree and tree parameters was expressed using linear regression models. The model based on *S. senegal* DBH measurements enabled an accurate estimation of gum yield from the study area woodlands. However, previous studies have indicated that gum yield not only depends on stem diameter but also on the tapping intensity, number of tree branches, the direction of tapping, and season (Wekesa et al., 2009; Alemu et al., 2013). Furthermore, all these three parameters are affected by environmental and geographical factors such as rainfall, temperature, latitude and longitude, and soil conditions (Osorio et al., 2018; Ranaivoson et al., 2015), which might have a direct impact on the accuracy of the models. Our model based on DBH measurements provides new insights regarding the potential commercial development of gum arabic production in dryland areas as an off-farm activity to supplement the household economy of local communities together with the other associated gum- and resin-producing tree species. However, further models that include more ecological variables should be developed to extrapolate this potentiality to other understudied areas. Furthermore, the findings from this preliminary study could be used to estimate the gum arabic yield per tree and season in natural stands in the study area. Yield assessments should also be carried out for several seasons to determine the best tapping time/dates.

# Conclusions

# 6. Conclusions

- The results from the socioeconomic study provide baseline information about the ethnomycology of three ethnic groups in Ethiopia. The Amhara and Agew ethnic groups have a similar knowledge of wild mushrooms. This similarity is a result of their cultural exchanges, coexistence, and shared historical events. Furthermore, parallel responses were reported in many cases, such as the consumption of wild mushroom species by their parents or grandparents even though the respondents do not eat mushrooms, which will eventually lead to the loss of mycological knowledge in these two ethnic groups. By contrast, wild mushroom consumption is an integral part of the cultural knowledge of seasonal resources among the Sidama communities in the southern part of the country. Thus, the different traditional food compositions and recipes of the ethnic group should be further studied to ensure the potential value of wild mushroom species in the nutrition and food security role in the community.
- Although most of the individuals interviewed from the Amhara and Agew ethnic groups were not familiar with the wild mushrooms, they appreciated the food value of the mushrooms when they tasted them. Thus, the experience of tasting mushrooms by local communities has implications for poverty reduction through emphasizing locally available sources that enable rural households to diversify their food sources. Although we have tried to document the traditional knowledge and uses of wild mushroom species of three ethnic groups in Ethiopia, more studies are needed to ensure that much of the potential value of wild mushroom species and the ethnomycology knowledge of local communities is not lost. Such knowledge is part of the identity of these communities: knowledge of wild mushroom uses, linguistics, and harvesting can prevent their loss as modernization proceeds due to the dominance of hegemonic culture. Documentation of this knowledge could promote a revaluation of wild mushroom species as resources and promote their conservation. The knowledge and nomenclature of useful species could also be revitalized, and their use encouraged, and in doing so, wild mushroom species could make a greater contribution to food security, especially in a country like Ethiopia where food security is a country-wide issue.
- The study from *Tamarindus indica* highlighted that we have provided useful preliminary information on the variation in fruit yield in Tamarind of the two land-use types. Overall, there were a higher number of seedlings and large-sized Tamarind trees per hectare on farmland than in bushland, indicating that matured trees are well preserved on farmlands. However, we could not find tree size

classes between seedling and mature trees on farmland, whereas well-structured tree size classes were observed in bushland. This situation is likely to have long-term consequences for the population continuity of Tamarind trees on farmland in the long run. Thus, management plans to develop meaningful stand structures on farmland need to be established to ensure the continuity of the Tamarind population in the studied area, either by planting new Tamarind seedlings in specific plots sites or by conserving some of the existing seedlings during the preparation of the soils for new cultivation. Although higher Tamarind fruit yields were obtained from trees growing on farmland than in bushland in the Dello Menna district, the majority of farmland trees produced <5000 fruit per tree. However, the yield improvement can be done through deliberate selection of higher fruit yielder trees, taking into consideration that Tamarind could grow in more diverse dryland areas in Ethiopia. These strategies might also lead to the development of a sustainable fruit supply in rural areas for commercialization or subsistence use.

- Classificatory models revealed that, among the tree size variables, DBH was more suitable to predict the fruits yield category than the height of the trees. Similar results were observed for crown-related variables such as crown depth, crown volume, and crown surface in the farmlands, whereas crown diameter provides the best results in the bushlands. Finally, the number of branches was always significantly related, as we expected, with the yield classification. Thus, the obtained models indicated that the fruit yields of Tamarind trees could be improved through management under different tree sizes, crown structures, and tree branch categories.
- The third study highlighted the population status of *Senegalia senegal* trees in a dryland area where there is a good level of regeneration and the diameter distribution of individual *S. senegal* trees indicates that most are mature enough to be tapped. This indicates that gum arabic harvesting could be started in this area if appropriate management activities are applied. In addition, we have provided useful preliminary information on gum yield and a model based on *S. senegal* DBH measurements as a predictor for potential gum yield by this species. However, further modeling studies are needed to incorporate environmental and geographical factors that affect tree parameters to determine whether these factors influence the accuracy of the yield model. Further yield assessments should be carried out for several seasons to determine the best tapping time.
- Overall, this study provides baseline information that could be used for planning future economic development in the study area based on the use of NTFPs, mainly gum and resin-production,

through considering the multiple uses of gum- and resin-producing species. The findings from this study also provide baseline information about gum yield that could be used to promote the protection, conservation, planting, taping, or commercial use of the *S. senegal* trees in the studied area.

- The gum yield data could be used to estimate gum arabic yields per *S. senegal* tree per year in the study area at different density levels and could also be used to assist other developing countries with valuable but underutilized trees like *S. senegal* that produce NTFPs. However, before gum arabic production can begin, management plans need to be established for natural forests to ensure the continuity and sustainability of gum arabic production, either by limiting production levels or the number of stems in different DBH classes that can be tapped.

## 7. Conclusiones

- Los resultados del estudio socioeconómico proporcionan información de referencia sobre la etnomicología de tres grupos étnicos en Etiopía. Los grupos étnicos Amhara y Agew tienen un conocimiento similar sobre los setas silvestres. Esta similitud es el resultado de sus intercambios culturales, convivencia y eventos históricos compartidos. Además, se reportaron respuestas paralelas en muchos casos, como el consumo de especies de setas silvestres por parte de sus padres o abuelos a pesar de que los encuestados no comen setas, lo que eventualmente conducirá a la pérdida del conocimiento micológico en estos dos grupos étnicos. Por el contrario, el consumo de setas silvestres es una parte integral del conocimiento cultural de los recursos estacionales entre las comunidades Sidama en la parte sur del país. Por lo tanto, las diferentes composiciones y recetas de alimentos tradicionales del grupo étnico deben estudiarse más a fondo para garantizar el valor potencial de las especies de setas silvestres en el papel de la nutrición y la seguridad alimentaria en la comunidad.
- Aunque la mayoría de los individuos entrevistados de los grupos étnicos Amhara y Agew no estaban familiarizados con los hongos silvestres, apreciaron el valor alimenticio de las setas cuando los probaron. Por lo tanto, la experiencia de probar setas por parte de las comunidades locales tiene implicaciones para la reducción de la pobreza al enfatizar las fuentes locales disponibles que permiten a los hogares rurales diversificar sus fuentes de alimentos. Aunque hemos tratado de documentar el conocimiento tradicional y los usos de las especies de setas silvestres de tres grupos étnicos en Etiopía, se necesitan más estudios para garantizar que no se pierda gran parte del valor potencial de las especies de setas silvestres y el conocimiento etnomicológico de las comunidades locales. Dicho conocimiento es parte de la identidad de estas comunidades: el conocimiento de los usos, la lingüística y la recolección de las setas silvestres puede evitar su pérdida a medida que avanza la modernización debido al dominio de la cultura hegemónica. La documentación de este conocimiento podría promover una revalorización de las especies de setas silvestres como recursos y promover su conservación. También se podría revitalizar el reconocimiento de especies útiles y alentar su uso, y al hacerlo, las especies de setas silvestres podrían hacer una mayor contribución a la seguridad alimentaria, especialmente en un país como Etiopía, donde la seguridad alimentaria es un problema a nivel nacional.

- El estudio *Tamarindus indica* destacó que hemos proporcionado información preliminar útil sobre la variación en el rendimiento de frutos en Tamarind de los dos tipos de uso de la tierra. En general, hubo un mayor número de plántulas y árboles de tamarindo de gran tamaño por hectárea en las tierras de cultivo que en los matorrales, lo que indica que los árboles maduros están bien conservados en las tierras de cultivo. Sin embargo, no pudimos encontrar clases de tamaño de árbol entre plántulas y árboles maduros en tierras de cultivo, mientras que se observaron clases de tamaño de árbol bien estructuradas en matorrales. Es probable que esta situación tenga consecuencias a largo plazo para la continuidad de la población de árboles de tamarindo en las tierras agrícolas a largo plazo. Por lo tanto, es necesario establecer planes de manejo para desarrollar estructuras de rodales significativas en tierras de cultivo para asegurar la continuidad de la población de Tamarindo en el área estudiada, ya sea plantando nuevas plántulas de Tamarindo en sitios de parcelas específicas o conservando algunas de las plántulas existentes durante la preparación de los suelos para nuevos cultivos. Aunque se obtuvieron mayores producciones de fruta de tamarindo de los árboles que crecen en tierras agrícolas que en los matorrales en el distrito de Dello Menna, la mayoría de los árboles de las tierras agrícolas produjeron <5000 frutas por árbol.
- Los modelos clasificatorios revelaron que, entre las variables de tamaño de árbol, el DAP era más adecuado para predecir la categoría de producción de frutos que la altura de los árboles. Se observaron resultados similares para las variables relacionadas con la copa, profundidad de la copa, el volumen de la copa y la superficie de la copa en las tierras de cultivo, mientras que el diámetro de la copa proporciona los mejores resultados en los matorrales. Finalmente, el número de ramas siempre estuvo relacionado significativamente, como esperábamos, con la clasificación de producción. Por lo tanto, los modelos obtenidos indicaron que las producciones de frutos de los árboles de Tamarindo podrían mejorarse mediante el manejo en diferentes tamaños de árboles, estructura de copa y categoría de rama de árbol. Además, la mejora de la producción se puede lograr mediante la selección deliberada de árboles con mayor producción de frutos, teniendo en cuenta que el tamarindo podría crecer en áreas de tierras secas más diversas en Etiopía. Estas estrategias también podrían conducir al desarrollo de un suministro sostenible de frutas en áreas rurales para comercialización o uso de subsistencia.
- El tercer estudio destacó el estado de la población de árboles de *Senegalia senegal* en una zona de tierras secas donde hay un buen nivel de regeneración y la distribución del diámetro de los

árboles de *S. senegal* individuales indica que la mayoría son lo suficientemente maduros para ser explotados. Esto indica que la recolección de goma arábiga podría iniciarse en esta área si se aplican las preliminar útil sobre el rendimiento de goma y un modelo basado en las mediciones de DAP de *S. senegal* como predictor de la produccion potencial de goma de esta especie. Sin embargo, se necesitan más estudios de modelado para incorporar factores ambientales y geográficos que afectan los parámetros de los árboles para determinar si estos factores influyen en la precisión del modelo de la producción. Se deben realizar más evaluaciones de rendimiento durante varias temporadas para determinar el mejor momento de extracción.

- En general, este estudio proporciona información de referencia que podría usarse para planificar el desarrollo económico futuro en el área de estudio con base en el uso de PFNM, principalmente producción de goma y resina, considerando los múltiples usos de las especies productoras de goma y resina. Los resultados de este estudio también brindan información de referencia sobre la producción de la goma arábica que podría usarse para promover la protección, conservación, plantación, encintado o uso comercial de los árboles de *S. senegal* en el área estudiada.
- Los datos de la producción de goma arábica podrían usarse para estimar los rendimientos de goma arábiga por árbol de *S. senegal* por año en el área de estudio a diferentes niveles de densidad y también podrían usarse para ayudar a otros países en desarrollo con árboles valiosos pero subutilizados como S. senegal que producen PFNM. Sin embargo, antes de que pueda comenzar la producción de goma arábiga, es necesario establecer planes de manejo para los bosques naturales para garantizar la continuidad y sostenibilidad de la producción de goma arábiga, ya sea limitando los niveles de producción o el número de picas en diferentes clases de DAP que se pueden aprovechar.

## 8. References


Abate MA. Review of Opportunities, Challenges and Future Directions of Forestry Development. Agricultural Research & Technology: Open Access Journal. 2020; 24(5):179-93.

Addis G. Wild and semi-wild edible plants of Hamar and Xonso (South Ethiopia) with emphasis on their ethnobotany and nutritional composition of selected species. Unpublished PhD thesis. Addis Ababa University. 2009.

Adhikari, M.K.; Devkota, S.; Tiwari, R.D. Ethnomycolgical knowledge on uses of wild mushrooms in western and central Nepal. Our Nat. 2005, 3, 13–19.

Agúndez, D.; Douma, S.; Madrigal, J.; Gómez-Ramos, A.; Vinceti, B.; Alía, R.; Mahamane, A. Conservation of food tree species in Niger: Towards a participatory approach in rural communities. For. Syst. 2016, 25.

Agwu, O.P.; Bakayoko, A.; Jimoh, S.O.; Jatto, S.O.S.; Porembski, S. Influences of Land use type and Dendrometric Variables on fruit production of Garcinia kola Heckel in Nigeria. Trees For. People 2020, 2, 100015.

Ahenkan, A.; Boon, E. Non-Timber Forest Products (NTFPs): Clearing the Confusion in Semantics. J. Hum. Ecol. 2011, 33, 1.

Alemu, A.; Yilma, Z.; Eshete, A.; Dejene, T. Growth performance and gum Arabic production of Acacia Senegal in northwest lowlands of Ethiopia. J. For. Res. 2013, 24, 471–476.

Anegbeh, P.O.; Usoro, C.; Ukafor, V.; Tchoundjeu, Z.; Leakey, R.R.B.; Schreckenberg, K. Domestication of Irvingia gabonensis: 3. Phenotypic variation of fruits and kernels in a Nigerian village. Agrofor. Syst. 2003, 58, 213–218.

Anonymous. Ethiopia: National Conservation Strategy, Phase I Report. Ethiopian Environmental Authority, 1997. Addis Abeba.

Antonín, V. Flora of Tropical Africa, Volume 1: Monograph of Marasmius, Gloiocephala, Palaeocephala and Setulipes in Tropical Africa; National Botanic Garden: Meise, Belgium, 2007; 177p.

Arnold JM, Pérez MR. Can non-timber forest products match tropical forest conservation and development objectives? Ecological economics. 2001 Dec 1;39(3):437-47.

Asefa M, Cao M, He Y, Mekonnen E, Song X, Yang J. Ethiopian vegetation types, climate and topography. Plant Diversity. 2020 Aug 1;42(4):302-11.

Asfaw, Z.; Tadesse, M. Prospects for sustainable use and development of wild food plants in Ethiopia. Econ. Bot. 2001, 55, 47–62.



Asfaw, Z.; Tadesse, M. Prospects for sustainable use and development of wild food plants in Ethiopia. Econ. Bot. 2001, 55, 47–62.

Asfaw, Z.; Tadesse, M. Prospects for sustainable use and development of wild food plants in Ethiopia. Econ. Bot. 2001, 55, 47–62.

## References


Assefa, A.; Abebe, T. Wild edible trees and shrubs in the semi-arid lowlands of Southern Ethiopia. J. Sci. Dev. 2010, 1, 5–19.

Avocèvou-Ayisso, C.; Sinsin, B.; Adégbidi, A.; Dossou, G.; Van Damme, P. Sustainable use of non-timber forest products: Impact of fruit harvesting on Pentadesma butyracea regeneration and financial analysis of its products trade in Benin. For. Ecol. Manag. 2009, 257, 1930–1938.

Awas, T.; Asfaw, Z.; Nordal, I.; Demissew, S. Ethnobotany of Berta and Gumuz people in western Ethiopia. Biodiversity 2010, 11, 45–53.

Azene, B.; Birnie, A.; Tengnas, B. Useful Trees and Shrubs for Ethiopia. Identification, Propagation and Management for Agricultural and Pastoral Communities; Regional Soil Conservation Unit (RSCU), Swedish International Development Authority: Nairobi, Kenya, 1993.

Bekele, M. Forest Plantations and Woodlots in Ethiopia; African Forest Forum: Nairobi, Kenya, 2011; Volume 1, p. 52.

Bekele, M.; Lemenih, M. Participatory Forest Management Best Practices, Lesson Learnt and Participatory Forest Management Best Practices, Lesson Learnt and challenges encountered: The Ethiopian and Tanzanian Experiences; Farm Africa/SOS-Sahel: Addis Ababa, Ethiopia, 2008.

Belcher BM. Forest product markets, forests and poverty reduction. International Forestry Review. 2005 Jun 1;7(2):82-9.

Berit, G., Linder, P. Species richness, endemism and species composition in the tropical Afroalpine flora. Alpine Bot. 2014, 124 (2), 165e177.

Beza, Z.B. Challenges and prospects of community-based ecotourism development in Lake Zengena and its environs, North West Ethiopia. Afr. J. Hosp. Tour. Leis. 2017, 6, 1–12.

Bharucha Z, Pretty J. The roles and values of wild foods in agricultural systems. Philosophical Transactions of the Royal Society B: Biological Sciences. 2010 Sep 27;365(1554):2913-26.

Boa, E. Wild Edible Fungi: A Global Overview of Their Use and Importance to People; Non-Wood Forest Products No. 17; FAO: Rome, Italy, 2004; p. 147.

Bongers F, Tennigkeit T, editors. Degraded forests in Eastern Africa: management and restoration. Earthscan; 2010 Sep 23.

Borah, N.; Semwal, R.L.; Garkoti, S.C. Ethnomycological knowledge of three indigenous communities of Assam, India. Indian J. Tradit. Knowl. 2018, 17, 327–335.

Cai M, Pettenella D, Vidale E. Income generation from wild mushrooms in marginal rural areas. Forest Policy and Economics. 2011 Mar 1;13(3):221-6.

Chang, Y.S.; Lee, S.S. Utilisation of macrofungi species in Malaysia. Fungal Divers. 2004, 15, 15–22.

Chikamai, B.; Tchatat, M.; Tieguhong, J.; Ndoye, O. Forest Management for Non-Wood Forest Products and Services in SubSaharan Africa. Discov. Innov. 2009, 21.

Chivaura-Mususa, C.; Campbell, B.; Kenyon, W. Special Section: Land Use Options in Dry Tropical Woodland Ecosystems in Zimbabwe. Ecol. Econ. 2000, 33, 395–400.

Cunningham AB. Non-timber products and markets: Lessons for export-oriented enterprise development from Africa. InNon-timber forest products in the global context 2011 (pp. 83-106). Springer, Berlin, Heidelberg.

Cunningham, A. Applied Ethnobotany: People, Wild Plant Use and Conservation, 1st ed.; Routledge: Oxfordshire, UK, 2001.

da Silva Falcao MP, Gerald L, Joseph S, Ribeiro N. Evaluating the Effect of Non-Timber Forest Products on Rural Livelihoods in Macula-Marrupa Corridor Niassa Special Reserve, Mozambique: Implication for Income and Food Security. (2021)

Dansi A, Adjatin A, Adoukonou-Sagbadja H, Faladé V, Yedomonhan H, Odou D, Dossou B. Traditional leafy vegetables and their use in the Benin Republic. Genetic Resources and Crop Evolution. 2008 Dec;55(8):1239-56.

Dejene, T.; Agamy, M.S.; Agúndez, D.; Martín-Pinto, P. Ethnobotanical Survey of Wild Edible Fruit Tree Species in Lowland Areas of Ethiopia. Forests 2020, 11, 177.

Dejene, T.; Lemenih, M.; Bongers, F. Manage or convert Boswellia woodlands? Can frankincense production payoff? J. Arid Environ. 2013, 89, 77–83.

Dejene, T.; Mohamed, O.; Adamu, H. Stand status and yield economics of Acacia Senegal (l) wild at Abderafi, North Western Ethiopia. Asian J. Agric. Biol. 2014, 2, 129–136.

Dejene, T.; Oria-de-Rueda, J.A.; Martín-Pinto, P. Edible wild mushrooms of Ethiopia: Neglected non-timber forest products. Rev. Fitotec. Mex. 2017b, 40, 391–397.

Dejene, T.; Oria-de-Rueda, J.A.; Martín-Pinto, P. Fungal diversity and succession following stand development in Pinus patula Schiede ex Schltdl. & Cham. plantations in Ethiopia. For. Ecol. Manag. 2017, 395, 9–18.

Dejene, T.; Oria-de-Rueda, J.A.; Martín-Pinto, P. Wild mushrooms in Ethiopia: A review and synthesis for future perspective. For. Syst. 2017a, 26, eR04.

Dejene, T.; Oria-de-Rueda, J.A.; Martín-Pinto, P. Wild mushrooms in Ethiopia: A review and synthesis for future perspective. For. Syst. 2017, 26, eR04.

Delang CO. Ecological succession of usable plants in an eleven-year fallow cycle in northern Lao PDR. Ethnobotany Research and Applications. 2007 Dec 31;5:331-50.

Demissew S, Cribb P, Rasmussen F. Field guide to Ethiopian orchids. Royal Botanic Gardens, Kew; 2004.

Demissew, S., Nordal, I. Aloes and Lilies of Ethiopia and Eritrea. Shama Books, Addis Ababa, Ethiopia, 2010.

Dhyani D, Maikhuri RK, Rao KS, Kumar L, Purohit VK, Sundriyal M, Saxena KG. Basic nutritional attributes of Hippophaerhamnoides (sea buckthorn) populations from Uttarakhand Himalaya, India. Current Science. 2007; 92:1148-1152.

# References


Diallo, B.O.; Mckey, D.; Chevallier, M.H.; Joly, H.I.; Hossaert-Mckey, M. Breeding system and pollination biology of the semidomesticated fruit tree, Tamarindus indica L. (Leguminosae: Caesalpinioideae): Implications for fruit production, selective breeding, and conservation of genetic resources. Afr. J. Biotechnol. 2008, 7, 4068–4075.

Didita, M.; Nemomissa, S.; Gole, T.W. Floristic and structural analysis of the woodland vegetation around Dello Menna, southeast Ethiopia. J. For. Res. 2010, 21, 395–408.



Didita, M.; Nemomissa, S.; Gole, T.W. Floristic and structural analysis of the woodland vegetation around Dello Menna, southeast Ethiopia. J. For. Res. 2010, 21, 395–408.



Djossa, B.A.; Fahr, J.; Wiegand, T.; Ayihouénou, B.E.; Kalko, E.K.; Sinsin, B.A. Land use impact on Vitellaria paradoxa C.F. Gaerten. stand structure and distribution patterns: A comparison of Biosphere Reserve of Pendjari in Atacora district in Benin. Agrofor. Syst. 2008, 72, 205–220.

Duchok, R.; Kent, K.; Khumbongmayum, A.; Ashish, P.; Paul, A. Population structure and regeneration status of medicinal tree Illicium griffithii in relation to disturbance gradient in temperate broad-leaved forest of Arunachal Pradesh. Curr. Sci. 2005, 89, 673–676.



Duchok, R.; Kent, K.; Khumbongmayum, A.; Ashish, P.; Paul, A. Population structure and regeneration status of medicinal tree Illicium griffithii in relation to disturbance gradient in temperate broad-leaved forest of Arunachal Pradesh. Curr. Sci. 2005, 89, 673–676.



Durazzo, A.; Lisciani, S.; Camilli, E.; Gabrielli, P.; Marconi, S.; Gambelli, L.; Aguzzi, A.; Lucarini, M.; Maiani, G.; Casale, G.; et al. Nutritional composition and antioxidant properties of traditional Italian dishes. Food Chem. 2017, 218, 70–77.

Ekandjo, L.K.; Chimwamurombe, P.M. Traditional medicinal uses and natural hosts of the genus Ganoderma in north-eastern parts of Namibia. J. Pure Appl. Microbiol. 2012, 6, 1139–1146.

Ella, S.B.E. Pour un Véritable Développement Durable de la Boucle du Dja: Contribution à L'enracinement de l'éco Sociologie; La Presses Universitaires de Yaoundé en coédition avec NENA: Sénégal, The Netherlands, 2017; ISBN 978-2-37015-625-9.

Ermias, L.; Ensermu, K.; Tamrat, B.; Haile, Y. Plant species composition and structure of the Mana Angetu mosit montane forest, south-eastern Ethiopia. J. East. Afr. Nat. Hist. 2008, 97, 165–185.

Eshete A, Teketay D, Hulten H. The socio-economic importance and status of populations of Boswellia papyrifera (Del.) Hochst. in northern Ethiopia: the case of North Gonder Zone. Forests, Trees and Livelihoods. 2005 Jan 1;15(1):55-74.

Eshete, A. The Frankincense Tree of Ethiopia: Ecology, Productivity and Population Dynamics; Wageningen University: Wageningen, The Netherlands, 2011.

Eshete, A. The Frankincense Tree of Ethiopia: Ecology, Productivity and Population Dynamics. Ph.D. Thesis, Wageningen University, Wageningen, The Netherlands, 2011. Available online: https://www.wur.nl/en/show/The-frankincense-tree-of-Ethiopia-ecology-productivity-and-population-dynamics.htm (accessed on 17 June 2020).

Eshete, A.; Sterck, F.; Bongers, F. Diversity and production of Ethiopian dry woodlands explained by climateand soil-stress gradients. For. Ecol. Manag. 2011, 261, 1499–15

Eshete, A.; Teketay, D.; Hulten, H. The socio-economic importance and status of populations of Boswellia papyrifera (Del.) Hochst. in northern Ethiopia: The case of North Gonder Zone. For. Trees Livelihoods 2005, 15, 55–74.

Fandohan, B.; Assogbadjo, A.E.; Kakaï, R.G.; Sinsin, B. Geographical distribution, tree density and fruit production of Tamarindus indica L. (Fabaceae) across three ecological regions in Benin. Fruits 2011, 66, 65–78.

Fang B. Poverty and biodiversity in rural areas based on two investigations in Pujiang County, China. Journal of environmental management. 2009 Apr 1;90(5):1924-32.

Faye, M.D.; Weber, J.C.; Abasse, T.A.; Boureima, M.; Larwanou, M.; Bationo, A.B.; Diallo, B.O.; Sigué, H.; Dakouo, J.M.; Samaké, O.; et al. Farmers' preferences for tree functions and species in the west African sahel. For. Trees Livelihoods 2011, 20, 113–136.

Fentahun M, Hager H. Integration of indigenous wild woody perennial edible fruit bearing species in the agricultural landscapes of Amhara region, Ethiopia. Agroforestry systems. 2010 Jan;78(1):79-95.

Ferreira, I.C.F.R.; Vaz, J.A.; Vasconcelos, M.H.; Martins, A. Compounds from wild mushrooms with antitumor potential. Anticancer Agents Med. Chem. 2010, 10, 424–436.

Fortini LB. Integrated models show a transient opportunity for sustainable management by tropical forest dwellers. Forest Ecology and Management. 2019 Apr 15; 438:233-42.

Friis I, Thulin MA, Adsersen H, Buerger AM. Patterns of plant diversity and endemism in the Horn of Africa. Biol. Skr. 2005; 55:289-314.

Friis IB, Demissew S, Breugel PV. Atlas of the potential vegetation of Ethiopia. Det Kongelige Danske Videnskabernes Selskab; 2010.

Garbach, K.; Lubell, M.; DeClerck, F.A.J. Payment for Ecosystem Services: The roles of positive incentives and information sharing in stimulating adoption of silvopastoral conservation practices. Agric. Ecosyst. Environ. 2012, 156, 27–36.

Garibay-Orijel, R.; Caballero, J.; Estrada-Torres, A.; Cifuentes, J. Understanding cultural significance, the edible mushrooms case. J. Ethnobiol. Ethnomed. 2007, 3, 4.

Gasson PE, Lancaster CA, Young R, Redstone S, Miles-Bunch IA, Rees G, Guillery RP, Parker-Forney M, Lebow ET. WorldForestID: Addressing the need for standardized wood reference collections to support authentication analysis technologies; a way forward for checking the origin and identity of traded timber. Plants, People, Planet. 2021 Mar;3(2):130-41.

Gebauer, J.; Adam, Y.O.; Sanchez, A.C.; Darr, D.; Eltahir, M.E.S.; Fadl, K.E.M.; Fernsebner, G.; Frei, M.; Habte, T.-Y.; Hammer, K.; et al. Africa's wooden elephant: The baobab tree (Adansonia digitata L.) in Sudan and Kenya: A review. Genet. Resour. Crop. Evol. 2016, 63, 377–399.

Gebrehiwot K, Hundera K. Species composition, plant community structure and natural regeneration status of Belete moist evergreen montane forest, Oromia regional state, Southwestern Ethiopia. Momona Ethiopian Journal of Science. 2014 Apr 10;6(1):97-101.

Getachew, T.; Tamrat, B.; Sebsebe, D. Dryland woody vegetation along an altitudinal gradient on the eastern escarpment of Welo, Ethiopia. Ethiop. J. Sci. 2008, 31, 43–54.

Ghimire P, Pudasaini N, Lamichhane U. Status, Prospects and Challenges for Non-Timber Forest Products Conservation in Nepal: A Critical Review. Ghimire, P., Pudasaini, N. and Lamichhane, U.(2021). Status, Prospect and Challenges of NTFPs Conservation in Nepal: A Critical review. Grassroots Journal of Natural Resources. 2021 Mar 25;4(1):1-5.

Giday, M.; Asfaw, Z.; Woldu, Z. Medicinal plants of the Meinit ethnic group of Ethiopia: An ethnobotanical study. J. Ethnopharmacol. 2009, 124, 513–521.

Girmay, H.; Tewolde-Berhan, S.; Hishe, H.; Asfaw, Z.; Ruelle, M.; Power, A. Use and management of tamarind (Tamarindus indica L., Fabaceae) local morphotypes by communities in Tigray, Northern Ethiopia. For. Trees Livelihoods 2020, 29, 81–98.

Glück P. Theoretical perspectives for enhancing biological diversity in forest ecosystems in Europe. Forest Policy and Economics. 2000 Dec 1;1(3-4):195-207.

Gruenewald, H.; Brandt, B.K.V.; Schneider, B.U.; Bens, O.; Kendzia, G.; Hüttl, R.F. Agroforestry systems for the production of woody biomass for energy transformation purposes. Ecol. Eng. 2007, 29, 319–328.

Gryzenhout, M.; Roets, F.; de Villiers, R. Fungal conservation in Africa. Mycol. Balc. 2010, 7, 43–48.

Gujarati, D. Essentials of Econometrics, 4th ed.; McGraw-Hill: New York, NY, USA, 1992; 54p.

Gunasena, H.P.; Hughes, A. Tamarind: Tamarindus indica L.; International Centre for Underutilised Crops, University of Southampton: Southampton, UK, 2000.

Hagen BV, Fight RR. Opportunities for conservation-based development of nontimber forest products in the Pacific Northwest. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland OR. (1999).

Hajjar R, Cheek JZ, Jagger P, Kamoto J, Newton P, Oldekop J, Razafindratsima OH. Research frontiers on forests, trees, and poverty dynamics. Forest Policy and Economics. 2021 Oct 1;131:102554.

Hama, O.; Maes, E.; Guissou, M.; Ibrahim, D.; Barrage, M.; Parra, L.; Raspe, O.; De Kesel, A. Agaricus subsaharianus, une nouvelle espèce comestible et consomméeau Niger, au Burkina Faso et en Tanzanie. Crypto. Mycol. 2010, 31, 221–234.

Härkönen, M.; Niemelä, T.; Mbindo, K.; Kotiranta, H.; Pierce, G.D. Zambian mushrooms and mycology. Norrlinia 2015, 29, 1–5.

Hedberg, I.; Edwards, S. Flora of Ethiopia and Eritria; Addis Ababa and Asmara, Ethiopia: Uppsala, Sweden, 1989.

Heinemann, P. Champignons Récoltés au Congo Belge; Botanic Garden Meise: Meise, Belgium, 1956; Volume 5, pp. 99–119.

Héritier, M.; Hippolyte, N.; Cephas, M.; Hoffman, B.; Gallaher, T. Importance indices in ethnobotany. Ethnobot. Res. Appl. 2007, 5, 201–218.

Husen A, Bachheti RK, Bachheti A. Non-Timber Forest Products. 2021.

Jaenicke, H.; Hoschle-Zeledon, I. Strategic Framework for Underutilized Plant Species Research and Development; ICUC, Colombo and Global Facilitation Unit for Underutilized Species: Rome, Italy, 2006.

Jaenicke, H.; Hoschle-Zeledon, I. Strategic Framework for Underutilized Plant Species Research and Development; ICUC, Colombo and Global Facilitation Unit for Underutilized Species: Rome, Italy, 2006.

Jendrzejewski B. The evolving economic importance of Polish forests between 1918 and 1945. Rural History. 2021:1-1.

Jimoh SO, Amusa TO, Azeez IO. Population distribution and threats to sustainable management of selected non-timber forest products in tropical lowland rainforests of south western Nigeria. Journal of forestry research. 2013 Mar;24(1):75-82.

Jimoh SO, Amusa TO, Azeez IO. Population distribution and threats to sustainable management of selected non-timber forest products in tropical lowland rainforests of south western Nigeria. Journal of forestry research. 2013 Mar;24(1):75-82.

Kadhila-Muandingi, N.P. The Distribution, Genetic Diversity, and Uses of Ganoderma Mushrooms in Oshana and Ohangwena Regions of Northern Namibia. Master's Thesis, University of Namibia, Windhoek, Namibia, 2010. Available online: http://repository.unam.edu.na/handle/11070/525 (accessed on 17 June 2020).

Kakon, A.; Choudhury, M.B.K.; Saha, S. Mushroom Is an Ideal Food Supplement. J. Dhaka Natl. Med. Coll. Hosp. 2012, 18, 58–62.

Kamalebo, H.M.; Nshimba, H.; Wa, S.; Ndabaga, C.M. Uses and importance of wild fungi: Traditional knowledge from the Tshopo province in the Democratic Republic of the Congo. J. Ethnobiol. Ethnomed. 2018, 14, 13.

Kaoma H, Shackleton CM. The direct-use value of urban tree non-timber forest products to household income in poorer suburbs in South African towns. Forest Policy and Economics. 2015 Dec 1;61:104-12.

Karki M, Rawat RB. SUSTAINABLE FOREST MANAGEMENT| Definitions, Good Practices and Certification. 2004

Kassa H, Campbell B, Sandewall M, Kebede M, Tesfaye Y, Dessie G, Seifu A, Tadesse M, Garedew E, Sandewall K. Building future scenarios and uncovering persisting challenges of participatory forest management in Chilimo Forest, Central Ethiopia. Journal of environmental management. 2009 Feb 1;90(2):1004-13.

Kassa, H.; Campbell, B.; Sandewall, M.; Kebede, M.; Tesfaye, Y.; Dessie, G.; Seifu, A.; Tadesse, M.; Garedew, E.; Sandewall, K. Building future scenarios and uncovering persisting challenges of participatory forest management in Chilimo Forest, Central Ethiopia. J. Environ. Manag. 2009, 90, 1004–1013.

Kebede, M.; Kanninen, M.; Yirdaw, E.; Lemenih, M. Vegetation structural characteristics and topographic factors in the remnant moist Afromontane forest of Wondo Genet, south central Ethiopia. J. For. Res. 2013, 24, 419–430.

## *References*


Kent, M.; Coker, P. Vegetation Description and Analysis: A practical Approach; Belhaven Press: London, UK, 1992.

Kevin, M. Quantitative Analysis by the Point-Centered Quarter Method. arXiv 2015, arXiv:1010.3303v2.


Kevin, M. Quantitative Analysis by the Point-Centered Quarter Method. arXiv 2015, arXiv:1010.3303v2.


Kimondo, J.M.; Okia, C.A.; Agea, J.G.; Abohassan, R.A.A.; Mulatya, J.; Teklehaimanot, Z. Estimating fruit yield from Vitex payos (Lour) merr. in semi-arid eastern province of Kenya: Application of allometric equations. Res. J. Appl. Sci. 2011, 6, 153–162.

Kinge, T.R.; Apalah, N.A.; Nji, T.M.; Acha, A.N.; Mih, A.M. Species richness and traditional knowledge of macrofungi (mushrooms) in the Awing Forest Reserve and communities, Northwest Region, Cameroon. J. Mycol. 2017, 2017, 2809239.

Lemenih M, Kassa H. Re-greening Ethiopia: history, challenges and lessons. Forests. 2014 Aug;5(8):1896-909.

Lemenih, M.; Kassa, H. Re-greening Ethiopia: History, challenges and lessons. Forests 2014, 5, 1896–1909.

Lemenih, M.; Kassa, H. Socio-economic and environmental significance of dry land resources of Ethiopia and their development challenges. J. Agric. Dev. 2010, 1, 71–91.

Lemenih, M.; Olsson, M.; Karltun, E. Comparison of soil attributes under Cupressus lusitanica and Eucalyptus saligna established on abandoned farmlands with continuously cropped farmlands and natural forest in Ethiopia. For. Ecol. Manag. 2004, 195, 57–67.

Levang, P.; Lescuyer, G.; Noumbissi, D.; Déhu, C.; Broussolle, L. Does gathering really pay? Case studies from forest areas of the East and South regions of Cameroon. For. Trees Livelihoods 2015, 24, 128–143.

Local Food-Nutraceuticals Consortium. Understanding local Mediterranean diets: a multidisciplinary pharmacological and ethnobotanical approach. Pharmacological Research. 2005 Oct 1;52(4):353-66.

López-Feldman A, Mora J, Taylor JE. Does natural resource extraction mitigate poverty and inequality? Evidence from rural Mexico and a Lacandona Rainforest Community. Environment and Development Economics. 2007 Apr;12(2):251-69.

Łuczaj Ł, Köhler P, Pirożnikow E, Graniszewska M, Pieroni A, Gervasi T. Wild edible plants of Belarus: from Rostafiński's questionnaire of 1883 to the present. Journal of ethnobiology and ethnomedicine. 2013 Dec;9(1):1-8.

Lulekal E, Asfaw Z, Kelbessa E, Van Damme P. Wild edible plants in Ethiopia: a review on their potential to combat food insecurity. Afrika focus. 2011 Feb 25;24(2):71-122.

Mahonya S, Shackleton CM, Schreckenberg K. Non-timber forest product use and market chains along a deforestation gradient in southwest Malawi. Frontiers in Forests and Global Change. 2019 Nov 8;2:71.

Maikhuri RK, Rao KS, Saxena KG. Bioprospecting of wild edibles for rural development in the central Himalayan mountains of India. Mountain Research and Development. 2004 May;24(2):110-3.

Manning, A.D.; Fischer, J.; Lindenmayer, D.B. Scattered trees are keystone structures—Implications for conservation. Biol. Conserv. 2006, 132, 311–321.

Marconi, S.; Durazzo, A.; Camilli, E.; Lisciani, S.; Gabrielli, P.; Aguzzi, A.; Gambelli, L.; Lucarini, M.; Marletta, L. Food composition databases: Considerations about complex food matrices. Foods 2018, 7, 2.

Marshall E, Newton AC, Schreckenberg K. Commercialisation of non-timber forest products: first steps in analysing the factors influencing success. International Forestry Review. 2003 Jun 1;5(2):128-37.

Masozera MK, Alavalapati JR. Forest dependency and its implications for protected areas management: a case study from the Nyungwe Forest Reserve, Rwanda. Scandinavian Journal of Forest Research. 2004 Jan 1;19(S4):85-92.

Mattalia G, Quave CL, Pieroni A. Traditional uses of wild food and medicinal plants among Brigasc, Kyé, and Provençal communities on the Western Italian Alps. Genetic Resources and Crop Evolution. 2013 Feb;60(2):587-603.

Mattila, P.; Könkö, K.; Eurola, M.; Pihlava, J.M.; Astola, J.; Vahteristo, L.; Hietaniemi, V.; Kumpulainen, J.; Valtonen, M.; Piironen, V. Contents of vitamins, mineral elements, and some phenolic compounds in cultivated mushrooms. J. Agric. Food Chem. 2001, 49, 2343–2348.

Mbuvi D, Boon E. The livelihood potential of non-wood forest products: The case of Mbooni Division in Makueni District, Kenya. Environment, Development and sustainability. 2009 Oct;11(5):989-1004.

McSweeney K. Who is “forest-dependent”? Capturing local variation in forest-product sale, Eastern Honduras. The Professional Geographer. 2002 May 1;54(2):158-74.

MEFCC (Ministry of Environment, Forest and Climate Change). National Forest Sector Development Program, Ethiopia Volume II: Program Pillars, Action Areas and Targets 2018.

MEFCC. National Forest Sector Development Program, Ethiopia. Volume II: Program. Pillars, Action Areas and Targets; Ministry of Environment, Forestry, and Climate Change: Addis Ababa, Ethiopia, 2018.

Mekonnen, Z.; Kassa, H.; Woldeamanuel, T.; Asfaw, Z. Analysis of observed and perceived climate 623 change and variability in Arsi Negele District, Ethiopia. Environ. Dev. Sustain. 2018, 20, 1191–1212.

Melaku, E.; Ewnetu, Z.; Teketay, D. Non-timber forest products and household incomes in Bonga forest area, southwestern Ethiopia. J. For. Res. 2014, 25, 215–223.

Mengistu, F.; Hager, H. Wild edible fruit species cultural domain, informant species competence and preference in three districts of Amhara region, Ethiopia. Ethnobot. Res. Appl. 2008, 6, 487–502.

Mengistu, T.; Teketay, D.; Hulten, H.; Yemshaw, Y. The role of enclosures in the recovery of woody vegetation in degraded dryland hillsides of central and northern Ethiopia. J. Arid Environ. 2005, 60, 259–281.

Miller, K.; Dietz, J.M. Fruit yield, not DBH or fruit crown volume, correlates with time spent feeding on fruits by wild Leontopithecus rosalia. Int. J. Primatol. 2004, 25, 27–39.

Morris, B. An annotated check-list of the macrofungi of Malawi. Kirkia 1990, 13, 323–364. 57. Pegler, D.; Rayner, R. A contribution to the Agaric flora of Kenya. Kew Bull. 1969, 23, 347–412.

Mujawamariya G, Karimov AA. Importance of socio-economic factors in the collection of NTFPs: the case of gum Arabic in Kenya. Forest Policy and Economics. 2014 May 1;42:24-9.

Muleta, D.; Woyessa, D.; Teferi, Y. Mushroom consumption habits of Wacha Kebele residents, southwestern Ethiopia. Glob. Res. J. Agric. Biol. Sci. 2013, 4, 6–16.

Myers N. Tropical forests: much more than stocks of wood. Journal of tropical ecology. 1988 May;4(2):209-21.

NBSAP (National biodiversity strategy and action plan). December 2005. Adiss Ababa, Ethiopia.

Neumann RP, Hirsch E. Commercialisation of non-timber forest products: review and analysis of research.2000.

Noroozi J, Talebi A, Doostmohammadi M, Rumpf SB, Linder HP, Schneeweiss GM. Hotspots within a global biodiversity hotspot-areas of endemism are associated with high mountain ranges. Scientific reports. 2018 Jul 9;8( 1):1-0.

Ogbazghi, W.; Rijkers, T.; Wessel, M.; Bongers, F. Distribution of the frankincense tree Boswellia papyrifera in Eritrea: The role of environment and land use. J. Biogeogr. 2006, 33, 524–535.

Okia, C.A.; Agea, J.G.; Kimondo, J.M.; Abohassan, R.A.A.; Okiror, P.; Obua, J.; Teklehaima, Z. Use and Management of Balanites aegyptiaca in Drylands of Uganda. Res. J. Biol. Sci. 2011, 6, 15–24.

Ongoche, I.C.; Otieno, D.J.; Oluoch-Kosura, W. Assessment of factors influencing smallholder farmers' adoption of mushroom for livelihood diversification in Western Kenya. Afr. J. Agric. Res. 2017, 12, 2461–2467.

Osorio, V.Á.; Muriel, S.B.; Torres, J.M.C. Morphoagronomic characterization of Tamarindus indica L. in orchards of tropical dry forest from Antioquia (Colombia). Biodivers. Int. J. 2018, 2, 396–403.

Pailler, S.; Naidoo, R.; Burgess, N.D.; Freeman, O.E.; Fisher, B. Impacts of Community-Based Natural Resource Management on Wealth, Food Security and Child Health in Tanzania. PLoS ONE 2015, 10, e0133252.

Paul, A.; Khan, M.L.; Das, A.K. Population structure and regeneration status of rhododendrons in temperate mixed broad-leaved forests of western Arunachal Pradesh, India. Geol. Ecol. Landsc. 2019, 3, 168–186.

Peters CM, Gentry AH, Mendelsohn RO. Valuation of an Amazonian rainforest. Nature. 1989 Jun;339(6227):655-6.

Peters CM, Gentry AH, Mendelsohn RO. Valuation of an Amazonian rainforest. Nature. 1989 Jun;339(6227):655-6.

Quave CL, Pieroni A. A reservoir of ethnobotanical knowledge informs resilient food security and health strategies in the Balkans. Nature Plants. 2015 Feb 2;1(2):1-6.

Rammeloo, J.; Walleyn, R. The edible fungi of Africa south of the Sahara: A literature survey. Scr. Bot. Belg. 1993, 5, 1–62.

Ranaivoson, T.; Brinkmann, K.; Rakouth, B.; Buerkert, A. Distribution, biomass and local importance of tamarind trees in south-western Madagascar. Glob. Ecol. Conserv. 2015, 4, 14–25.

Razafindratsima OH, Kamoto JF, Sills EO, Mutta DN, Song C, Kabwe G, Castle SE, Kristjanson PM, Ryan CM, Brockhaus M, Sunderland T. Reviewing the evidence on the roles of forests and tree-based systems in poverty dynamics. Forest Policy and Economics. 2021 Oct 1;131:102576.

Ryvarden, L.; Piearce, G.D.; Masuka, A.J. An Introduction to the Larger Fungi of South Central Africa; Baobab Books: Harare, Zimbabwe, 1994; Available online: https://agris.fao.org/agris-search/search.do?recordID=XF2016048164 (accessed on 17 June 2020).

Saha D, Sundriyal RC. Utilization of non-timber forest products in humid tropics: Implications for management and livelihood. Forest Policy and Economics. 2012 Jan 1;14(1):28-40.

Saha, D.; Sundriyal, R. Prioritization of non-timber forest produces for income generation: A participatory approach. J. Non-Timber For. Prod. 2010, 17, 387–394.

Saha, D.; Sundriyal, R. Prioritization of non-timber forest produces for income generation: A participatory approach. J. Non-Timber For. Prod. 2010, 17, 387–394.

Sarma, T.; Sarma, I.; Patiri, B. Wild edible mushrooms used by some ethnic tribes of Western Assam. Bioscan 2010, 3, 613–625. [

Sasidharan S. Teak Plantations and Wood Production. InThe Teak Genome 2021 (pp. 13-25). Springer, Cham.

Saxena NC. Livelihood Diversification and Non-Timber Forest Products in Orissa: Wider Lessons on the Scope for Policy Change?. London: Overseas Development Institute; 2003 Aug.

Scarpa GF. Wild food plants used by the indigenous peoples of the South American Gran Chaco: A general synopsis and intercultural comparison. (2009).

SCBD (Secretariat of the Convention on Biological Diversity). Sustainable management of non-timber forest resources. CBD Technical Series no. 6, 2001. Biotropica, 48(2): 1-33. 2014.

Schneider, R.; Calama, R.; Martin-Ducup, O. Understanding tree-to-tree variations in stone pine (Pinus pinea L.) cone production using terrestrial laser scanner. Remote Sens. 2020, 12, 173.

Schwartzman S, Moreira A, Nepstad D. Rethinking tropical forest conservation: perils in parks. Conservation Biology. 2000 Oct 18;14(5):1351-7.

Semwal, K.C.; Lemma, H.; Dhyani, A.; Equar, G.; Amhare, S. Mushroom: Nature’s treasure in Ethiopia. Momona Ethiop. J. Sci. 2014, 6, 138–147.

Senaratne A, Abeygunawardena P, Jayatilake W. Changing role of non-timber forest products (NTFP) in rural household economy: the case of Sinharaja World Heritage site in Sri Lanka. Environmental Management. 2003 Nov;32(5):559-71.

Senbeta, F. Biodiversity and ecology of Afromontane rainforests with wild Coffea arabica L. populations in Ethiopia. Ecol. Dev. Ser. 2006, 36, 1–9.

Senbeta, F.; Teketay, D. Regeneration of indigenous woody species under the canopies of tree plantations in Central Ethiopia. Trop. Ecol. 2001, 42, 175–185.

Shackleton C, Shackleton S. The importance of non-timber forest products in rural livelihood security and as safety nets: a review of evidence from South Africa. S Afr J Sci. 2004;100(11 and 12):658–64.

Shackleton CM, Shackleton SE, Buiten E, Bird N. The importance of dry woodlands and forests in rural livelihoods and poverty alleviation in South Africa. Forest policy and economics. 2007 Jan 1;9(5):558-77.

Shackleton S, Delang CO, Angelsen A. From subsistence to safety nets and cash income: exploring the diverse values of non-timber forest products for livelihoods and poverty alleviation. InNon-timber forest products in the global context 2011 (pp. 55-81). Springer, Berlin, Heidelberg.

Shackleton S., Shackleton C., Shanley P. et al. (eds.). Non-Timber Forest Products in the Global Context, Tropical Forestry 7, Springer-Verlag Berlin Heidelberg 2011.

Shackleton, C.M.; Shackleton, S.E. Household wealth status and natural resource use in the Kat River valley, South Africa. Ecol. Econ. 2006, 57, 306–317.

Shanley P, Pierce AR, Laird SA, Binnqüist CL, Guariguata MR. From lifelines to livelihoods: Non-timber forest products into the twenty-first century. Tropical Forestry Handbook. Berlin Heidelberg: Springer-Verlag. 2015.

Shiva MP, Verma SK. Approaches to sustainable forest management and biodiversity conservation. International Book Distributors; 2002.

Shiva MP. Technology scenario in asia-pacific forestry sector. APFSOS Working Paper no. 25 Forestry Policy and Planning Division. 1993.

Shumi, G. The Structure and Regeneration Status of Tree and Shrub Species of Chilimo Forest Ecological Sustaibablity Indicators for Participatory Forest Managemet in Oromiya, Ethiopia Msc thesis. University of Dreseden, Germany. 2009.

Shumi, G. The Structure and Regeneration Status of Tree and Shrub Species of Chilimo Forest Ecological Sustainability Indicators for Participatory Forest Management (PFM) in Oromia, Ethiopia. (2009) Available online: https://agris.fao.org/agris search/search.do?recordID=ET2008000082 (accessed on 17 June 2020).

Singer, R. Marasmius. In Flore Iconographique des Champignons du Congo; National Botanic Garden of Belgium: Meise, Belgium, 1965; Volume 14, pp. 253–278.

Soromessa, T.; Teketay, D.; Sebsebe, D. Ecological study of the vegetation in Gamo Gofa zone, southern Ethiopia. Trop. Ecol. 2004, 45, 209–221.

Stanley D, Voeks R, Short L. Is non-timber forest product harvest sustainable in the less developed world? A systematic review of the recent economic and ecological literature. Ethnobiology and Conservation. 2012 Oct 11;1.

Stanley D, Voeks R, Short L. Is non-timber forest product harvest sustainable in the less developed world? A systematic review of the recent economic and ecological literature. Ethnobiology and Conservation. 2012 Oct 11;1.

Stoian D. Making the best of two worlds: rural and peri-urban livelihood options sustained by nontimber forest products from the Bolivian Amazon. World Development. 2005 Sep 1;33(9):1473-90.

Suleiman MS, Wasonga VO, Mbau JS, Suleiman A, Elhadi YA. Non-timber forest products and their contribution to households income around Falgore Game Reserve in Kano, Nigeria. Ecological Processes. 2017 Dec;6(1):1-4.

Sun, S.; Gao, W.; Lin, S.; Zhu, J.; Xie, B.; Lin, Z. Analysis of genetic diversity in Ganoderma population with a novel molecular marker SRAP. Appl. Microbiol. Biotechnol. 2006, 72, 537–543.

Sunderlin WD, Dewi S, Puntodewo A, Müller D, Angelsen A, Epprecht M. Why forests are important for global poverty alleviation: a spatial explanation. Ecology and society. 2008 Dec 1;13(2).

Sundriyal, M.; Sundriyal, R. Wild edible plants of the Sikkim Himalaya: Nutritive values of selected species. Econ. Bot. 2001, 55, 377–390.

Sundriyal, M.; Sundriyal, R.C. Structure, phenology, fruit yield, regeneration and marketing status of some prominent ethnobiological plant species of the Sikkim Himalaya, India. J. Ethnobiol. 2004, 24, 113–138.

Takasaki Y, Barham BL, Coomes OT. Risk coping strategies in tropical forests: floods, illnesses, and resource extraction. Environment and Development Economics. 2004 May;9(2):203-24.

Takele, A. Analysis of Rice Profitability and Marketing Chain: The Case of Fogera District South Gondar Zone, Amhara National Regional State, Ethiopia: ILRI-IPMS. Available online: https://agris.fao.org/agrissearch/search.do?recordID=QT2016102236 (accessed on 19 December 2019).

Team, R.C. A Language and Environment for Statistical Computing; R Foundation for Statistical Computing: Vienna, Austria, 2020.

Teketay D, Eshete A. Status of indigenous fruits in Ethiopia. Review and Appraisal on the Status of Indigenous Fruits in Eastern Africa: A Report Prepared for IPGRI-SAFORGEN in the Framework of AFRENA/FORENESSA, Kenya Forestry Research Institute, Nairobi, Kenya. 2004:3-5.

Teketay, D., Senbeta, F., Maclachlan, M., Bekele, M. and Barklund, P. Edible Wild Plants in Ethiopia. Addis Ababa University Press, Addis Ababa. (2010).

Teketay, D.; Granström, A. Soil seed banks in dry Afromontane forests of Ethiopia. J. Veg. Sci. 1995, 6, 777–786.

Teketaye, D.; Limenih, M. Role of Forestry in Poverty Alleviation in Ethiopia; Wondo Genet College of Forestry: Shashemenie, Ethiopia, 2005.

Teklehaymanot T, Giday M. Ethnobotanical study of wild edible plants of Kara and Kwego semi-pastoralist people in Lower Omo River Valley, Debub Omo Zone, SNNPR, Ethiopia. Journal of ethnobiology and ethnomedicine. 2010 Dec;6(1):1-8.

Tesfaye, M.A.; Gardi, O.; Anbessa, T.B.; Blaser, J. Aboveground biomass, growth and yield for some selected introduced tree species, namely Cupressus lusitanica, Eucalyptus saligna and Pinus patula in Central Highlands of Ethiopia. J. Ecol. Environ. 2020, 44, 1–18.

Tewolde B. Diversity of the Ethiopian flora. Plant genetic resources of Ethiopia.. 1991:75-81.

Tibuhwa, D. Folk taxonomy and use of mushrooms in communities around Ngorongoro and Serengeti National Park, Tanzania. J. Ethnobiol. Ethnomed. 2012, 8, 36.

Tibuhwa, D.D. Termitomyces species from Tanzania, their cultural properties and unequalled basidiospores. J. Biol. Life Sci. 2012, 3, 140–159.

Tilahun, A. Structure and regeneration status of Menagesha Amba Mariam Forest in Central Highlands of Shewa, Ethiopia. Agric. For. Fish. 2015, 4, 184.

Tuno, N. Mushroom utilization by the Majangir, an Ethiopian tribe. Mycologist 2001, 15, 78–79.

Umaña-Hermosilla, B.; de la Fuente-Mella, H.; Elórtegui-Gómez, C.; Fonseca-Fuentes, M. Multinomial Logistic Regression to Estimate and Predict the Perceptions of Individuals and Companies in the Face of the COVID-19 Pandemic in the Ñuble Region, Chile. Sustainability 2020, 12, 9553.

Vantomme P. Forest products division. Forestry Department. Food and Agriculture Organization, Rome, Italy. 2003.

Vanzani P, Rossetto M, De Marco V, Sacchetti LE, Paoletti MG, Rigo A. Wild Mediterranean plants as traditional food: a valuable source of antioxidants. Journal of Food Science. 2011 Jan;76(1):C46-51.

Vedeld P, Angelsen A, Bojö J, Sjaastad E, Berg GK. Forest environmental incomes and the rural poor. Forest Policy and Economics. 2007 Apr 1;9(7):869-79.

Voeks R A. Ethnobotany.Chapter 26. In: The SageHandbook of Biogeography. A. Millington, M. Blumler, G. MacDonald, and U. Schickhoff (eds). Los Angeles, CA: Sage Publications, 2011. pp. 493-509.

Von Hagen B. Opportunities for conservation-based development of nontimber forest products in the Pacific Northwest. US Department of Agriculture, Forest Service, Pacific Northwest Research Station; 1999.

Wale, H.A.; Bekele, T.; Dalle, G. Plant community and ecological analysis of woodland vegetation in Metema Area, Amhara National Regional State, Northwestern Ethiopia. J. For. Res. 2012, 23, 599–607.

Wang, Y.; Titus, S.J.; LeMay, V.M. Relationships between tree slenderness coefficients and tree or stand characteristics for major species in boreal mixedwood forests. Can. J. For. Res. 1998, 28, 1171–1183.

Wassie, A.; Teketay, D.; Powell, N. Church forests in North Gonder administrative zone, Northern Ethiopia. For. Trees Livelihoods 2005, 15, 349–373.

Weinstein S, Moegenburg S. Acai palm management in the Amazon Estuary: Course for conservation or passage to plantations? Conservation and Society. 2004 Jul 1:315-46.

Wekesa, C.; Makenzi, P.; Chikamai, B.N.; Lelon, J.K.; Luvanda, A.M.; Muga, M. Gum Arabic yield in different varieties of Acacia senegal (L.) Willd in Kenya. Afr. J. Plant. Sci. 2009, 3, 263–276.

Welford L, Breton GL. Bridging the gap: Phytotrade Africa's experience of the certification of natural products. Forests, trees and livelihoods. 2008 Jan 1;18(1):69-79.

Worku, A.; Lemenih, M.; Fetene, M.; Teketay, D. Socio-economic importance of gum and resin resources in the dry woodlands of Borana, southern Ethiopia. For. Trees Livelihoods 2011, 20, 137–155.

Wubet T, Kottke I, Teketay D, Oberwinkler F. Mycorrhizal status of indigenous trees in dry Afromontane forests of Ethiopia. Forest ecology and management. 2003 Jul 3;179(1-3):387-99.

Yebeyen, D. Population Status of Acacia Senegal (Linne) Willdenow and Its Gum Quality in the Central Rift Valley of Ethiopia. Master's Thesis, Awassa University, Awassa, Ethiopia, 2006.

Zewdie, M.; Olsson, M.; Verwijst, T. Above-ground biomass production and allometric relations of Eucalyptus globulus Labill. coppice plantations along a chronosequence in the central highlands of Ethiopia. Biomass Bioenergy 2009, 33, 421–428.

Zewdie, M.; Olsson, M.; Verwijst, T. Above-ground biomass production and allometric relations of Eucalyptus globulus Labill. coppice plantations along a chronosequence in the central highlands of Ethiopia. Biomass Bioenergy 2009, 33, 421–428

# Original articles

## Original article - I

# Conocimiento Etnomicológico de tres grupos étnicos en Etiopía

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## Resumen

La información Etnomicológica se recopiló mediante entrevistas semi-estructuradas con miembros de los grupos étnicos Amhara, Agew y Sidama en Etiopía. Un total de 300 personas participaron en este estudio. También se realizaron expediciones por el bosque para investigar el hábitat e identificar especies de hongos silvestres útiles presentes en las áreas de estudio. Se identificaron un total de 24 especies útiles de hongos silvestres. Entre los tres grupos étnicos, los Sidama tienen el conocimiento etnomicológico más amplio y se registraron más de siete nombres vernáculos de especies de hongos útiles para este grupo. La recolección de setas comestibles es una práctica común entre los Sidama y generalmente la realizan mujeres y niños durante la principal temporada de lluvias, de junio a septiembre. Las setas comestibles se recolectan en bosques naturales, plantaciones, áreas de pastoreo, huertos y áreas pantanosas. En términos de usos medicinales, *Lycoperdon perlatum* y *Calvatia rubroflava* son tratamientos bien conocidos para heridas y enfermedades de la piel. Se desconoce el almacenamiento de la cosecha de especies de hongos silvestres. Los grupos étnicos Amhara y Agew expresaron una opinión similar en cuanto a uso y conocimiento de las setas comestibles. Ambos grupos étnicos informaron que aunque sus abuelos consumían especies de setas silvestres, ellos mismos no comen setas, lo que eventualmente podría representar una pérdida de conocimiento micológico en estos dos grupos étnicos. Esta incoherencia entre los grupos étnicos en cuanto a sus conocimientos también puede estar relacionada con la valoración social de los recursos de las setas, que podría mitigarse fácilmente mediante la sensibilización. Por lo tanto, la información de referencia obtenida en este estudio podría ser útil para futuras investigaciones y documentación, y para promover los beneficios etnomicológicos a diferentes grupos étnicos en países con entornos similares.

Palabras claves: *Setas; Enguday; etnomicología; taxonomía popular; Amhara; Agew y Sida*

*forests*

MDPI

*Article*

# Ethnomycological Knowledge of Three Ethnic Groups in Ethiopia

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**Abstract:** Ethnomycological information was gathered by conducting semi-structured interviews with members of the Amhara, Agew, and Sidama ethnic groups in Ethiopia. A total of 300 individuals were involved in this study. Forest excursions were also undertaken to investigate the habitat and to identify useful wild mushroom species present in the study areas. A total of 24 useful wild mushroom species were identified. Among the three ethnic groups, the Sidama have the most extensive ethnomycological knowledge and over seven vernacular names for useful fungal species were recorded for this group. Collecting mushrooms is common practice among the Sidama and usually carried out by women and children during the main rainy season from June to September. Useful mushrooms are collected in natural forests, plantation forests, grazing areas, home gardens, and swampy areas. In terms of medicinal uses, *Lycoperdon perlatum* Pers. and *Calvatia rubroflava* (Cragin) Lloyd. are well-known treatments for wounds and skin disease. Harvest storage of wild mushroom species is unknown. Respondents in the Amhara and Agew ethnic groups were similar in terms of their use and knowledge of mushrooms. Both ethnic groups reported that although wild mushroom species were consumed by their grandparents, they do not eat mushrooms themselves, which could eventually represent a loss of mycological knowledge in these two ethnic groups. Such inconsistency between ethnic groups in terms of their knowledge may also be linked to the social valuation of mushroom resources, which could easily be mitigated by raising awareness. Thus, the baseline information obtained in this study could be useful for further investigations and documentation, and to promote ethnomycological benefits to different ethnic groups in countries with similar settings.

**Keywords:** mushroom; Enguday; ethnomycology; folk taxonomy; Amhara; Agew and Sidama

## 1. Introduction

One of the world's biggest challenges is to secure sufficient food for all that is healthy, safe and of high quality, and to do so in an environmentally sustainable manner [1,2]. In this context, forest resources can play an important role as a source of food [3,4], by enhancing nutritional diversity [5,6] while maintaining diversity in natural systems [7]. Thus, in recent years, there has been growing attention focused on the sustainability of foods [4,8,9] and food systems, which has highlighted the need to conserve species diversity, mainly of foods from forest systems in many parts of the world [10,11].

Wild mushroom species are vital components of the livelihoods of rural people in different parts of the world [12,13]. Many of these mushrooms are collected because they are valuable non-timber forest products (NTFPs) [14,15], enabling people to overcome vulnerability to poverty and sustain their livelihoods through a reliable source of income [12]. This has shifted ethnomycology into a discipline in different parts of the world [14]. Globally, about 140,000 important mushroom species have been reported. In various cultures, mushrooms can serve as sources of food [14], medicine [16], enzymes and various industrial compounds [17]. They serve as also important composition of food and recipes for traditional foods and recipes [18,19]. In addition, mushrooms can serve in a recreational context and in myths and beliefs [20]. Nutritionally, mushrooms are an important source of proteins, vitamins, fats, carbohydrates, amino acids, and minerals [21,22], i.e., they are a good alternative or substitute for meat and fish [22–24].

Previous ethnomycological studies have shown that local knowledge of mushrooms varies with people's cultures and beliefs [25–27]. Within local communities, conventional knowledge is passed down from one generation to the next because this is the only way of safeguarding traditional knowledge [14,25,26]. The use of questionnaires to record traditional knowledge linked to mushrooms enables mushroom "use values" to be evaluated for a specific local community to identify cultural differences between communities [25,28,29].

In Ethiopia, mushrooms are wild edible resources and important NTFPs like that of wild edible fruits, particularly in the southern and southwestern parts of the country [30–32]. Despite poor scientific knowledge, wild mushroom utilization is a common traditional practice among different ethnic groups in Ethiopia [33,34]. Mushrooms, along with other wild edible resources, are used as a coping food during periods of food shortage in localities where they are used as food [31,35]. In some local markets, mushrooms are sold by local people to provide some income to supplement the household economy [36]. However, there are few ethnomycological reports on wild mushrooms. The available reports are scanty and contain only basic information about the existence and use of mushrooms at some community levels in the country [34,36,37]. Efforts made so far have either been of a review nature and/or cross-sectional [38,39]. This lack of documentation could make local mycological knowledge vulnerable [29]. Due to a continuing exodus of people from the countryside, local communities are gradually losing an important part of their traditional knowledge, particularly about wild mushroom species [24,26,29]. There is a genuine need to record and document local traditional knowledge and perceptions about useful wild mushrooms. Furthermore, due to their economic value, efforts are needed to integrate wild mushroom species as mainstream NTFPs in Ethiopia to ensure their conservation and enhance their value as source of nutrition to improve human welfare. Thus, assessing the various uses of wild mushroom species by local people is key to the better valorization of services provided by wild useful fungi [40]. This would also enable us to better elaborate participative management and conservation plans for these forests resources. This study has, therefore, sought to assess and document ethnomycological knowledge related to wild mushroom species of three ethnic groups from three different geographical areas in Ethiopia. Thus, our specific objectives were: (i) to identify valuable wild mushroom species in three study areas; (ii) to record the use value of wild mushroom species for each of the ethnic groups; (iii) to evaluate the status of wild mushroom species within local communities; and (iv) to identify the main threats and to assess how these threats vary across the three study areas.

## 2. Methods

### 2.1. Description of the Study Area

The study was conducted in the Amhara Region and the Southern Nations, Nationalities, and Peoples' Region (SNNPR) of Ethiopia where more than half of the ethnic groups of Ethiopia are reside and from which three ethnic groups were selected: namely, the Amhara in the Fogera Woreda, the Agew in the Banja Woreda and the Sidama in the Wondo Genet Woreda (Figure 1). These three ethnic groups had been identified in this study with the assumption that they are having good knowledge of the identification, variability, and use of locally available NTFPs. The Amhara and Agew ethnic groups occupy the center of the northern highlands of the Amhara region. They live in the same agro- ecological zone and share the same cultures, and languages. They both are sedentary farmers who practice mixed agriculture, including crop production and livestock rearing. The crop varieties grown locally in these woredas include teff (*Eragrostis tef* (Zucc) Trotter), sorghum (*Sorghum bicolor* (L.) Moench), maize (*Zea mays* L.), finger millet (*Eleusine coracana* (L.) Gaertn.) and beans (*Phaseolus vulgaris* L.). The Sidama ethnic group is one of the largest ethnic groups in the southern highlands. The population density in Wondo Genet is higher than that of Fogera or Banja, with about seven inhabitants per km$^2$. The majority of the Sidama practice mixed agriculture, integrating cash crops, such as khat (*Catha edulis* (Vahl) Endl.) sugar cane, and Ensete (*Enset ventricosum* (Welw.) Cheesman), with livestock production, including fishing from the nearby lake.

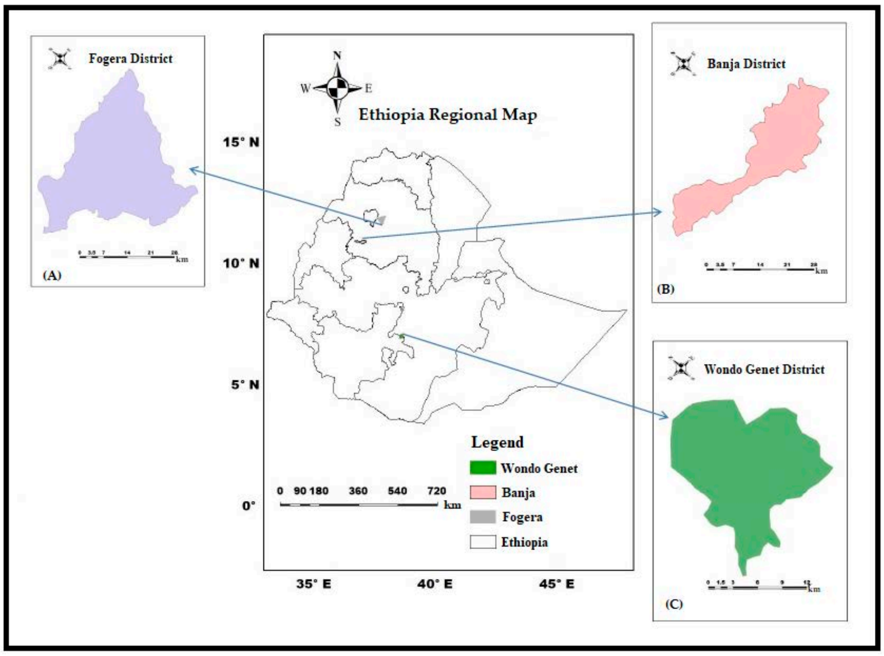


**Figure 1.** Location of the study woredas of the Amhara and Southern Nations, Nationalities, and Peoples' Region (SNNPR) in Ethiopia. (**A**) Fogera Woreda inhabited by the Amhara ethnic group; (**B**) Banja Woreda inhabited by the Agew ethnic group and (**C**) Wondo Genet Woreda inhabited by the Sidama ethnic group.

Wondo Genet, Banja and Fogera Woredas (Table 1) are characterized by high-altitude natural forests [41–44]. This high forest is dominated by Dry Afromontane forests [41,44], which are characterized by high humidity, a variable rainfall pattern and a prolonged dry season, making them complex and rich in biodiversity [45]. The main tree species found in these forests are *Juniperus procera* (Hochst. Ex Endl.), *Podocarpus falcatus* (Thubb.) Mirb.), *Hagenia abyssinica* (J.F.Gmel.), and *Olea africana* subsp. Cuspidata (Wall. & G.Don) Cif.) which are the main sources of timber in Ethiopia [46]. The Dry Afromontane forests also harbor various types of NTFPs [47], including edible fungi [38].

**Table 1.** Geographical description of the three study woredas.

| Study Woredas | Ethnic Group | Geographical Location | Altitude Range (m asl) | Mean Annual Precipitation (mm) | Mean Annual Temperature (°C) | References |
|---|---|---|---|---|---|---|
| Wondo Genet | Sidama | 7°06′ N & 38°37′ E | 1760–1920 | 1200 | 19 | [32] |
| Fogera | Amhara | 11°58′ N & 37°41′ E | 1780–2510 | 1245 | 20 | [43] |
| Banja | Agew | 11°10′ N & 36°15′ E | 1870–2570 | 1300 | 18 | [40] |

*2.2. Socioeconomic Data Collection*

This study presents three case studies as a type of ethnomycology research, each with various forms of socioeconomic data which were collected between January and August 2019. The data were collected from the primary data sources that involved the key informant interviews, focus group discussions and household interview methods. Details of the methods used followed Mekonnen et al. [48] and are described below:

The key informant interviews required people who were relatively knowledgeable about their community, local natural resources, the culture of their community, and the use of NTFPs to share their knowledge and experience with the interviewer and, therefore, suitable participants were selected for this interview. To select these key informants, a snowball method was used in which one key informant was contacted with the assistance of local administrators and community elders. Then, he/she would inform us of a second, the second would provide the name of a third and so on until a saturation number was reached [49–51]. In total, 17 elders (10 women and 7 men aged between 41 and 77 years old) from the three study areas (three from Banja, four from Fogera and the remaining 10 from Wondo Genet) served as key informants. During the study, each key informant was visited twice to verify the reliability of the data obtained. If information conveyed about a species during the first visit was not consistent with the information provided during the second visit, the information was considered unreliable and was rejected. The second visit also helped us to gather additional information from some of the participants that were not mentioned during the first interview. However, in most cases of the participants in the key informant discussion, no new information or themes were gathered during the second visit. Thus, this was a redundancy signals and the data collection was cease [50,51].

The focus group discussions were made up of representative members of the studied communities. The discussions were made up of three independent groups per kebele, the smallest administrative level in Ethiopia, and each group were consisted of ten individuals. When forming the groups, the populations in each study keble were first split into youths, women, and elders groups. Then, the overall samples consisted of some individuals from each spited groups. In each group the members are chosen randomly [49] to obtain varied knowledge and views, giving equal chances to youths, women, and elders for being selected as member of this study. The focus group discussions assessed the participants' feelings and opinions about wild mushrooms, the perceptions, beliefs, and myths attached to wild mushrooms, their marketability, knowledge of ecological niches and phenology/calendar use, as well as their opinion regarding resource degradation and the causes of degradation at the local level. At least one key informant was included in each group to triangulate information. The information collected via the key informant interviews and the focus group discussions was used to refine and compliment the information gathered via the household interviews in each of the study areas. The collected information was qualitatively interpreted and narrated in the Results and Discussion.

Household interview were conducted using a face-to-face semi-structured questionnaire interview. The households were selected purposively based on their gender and their dependence on the forest for their livelihood [49,52]. The questionnaire was constructed to obtain information relating to the objectives of the study and had been pretested with 15 randomly selected individuals from each study woredas. Based on the results of the pretest work, the questionnaires were modified as necessary. Enumerators were recruited from the study areas and the study objectives were explained to them. The enumerators were also trained in the methods of data collection and interviewing techniques. In total, 300 households from Wondo Genet, Banja, and Fogera woredas took part in the survey. The interviews were conducted in the Amharic language. In some cases, an interpreter conducted the surveys to ensure that the meaning of the questions was not changed. Interviews were conducted in a place where the informants were most comfortable. Information regarding the gathering, preparation, use, status/abundance, etc. of wild mushroom species and their marketability was also collected. Additional discussions were conducted with the households to understand the traditional use of mushrooms for medicinal purposes.

### *2.3. Wild Mushroom Species Collection*

Weekly wild mushroom resource assessments were undertaken in July and August in 2016 during the major rainy season in nearby remnant Dry Afromontane forests [39]. For the purpose, we established a total of nine sample plots in each study woredas, plots were established systematically about 250 m apart. Each plot covered an area of 100 $m^2$, with a rectangular shape (2 m × 50 m) [39]. During sampling, sample fruit bodies from encountered species in the sampling plots were collected and taken to the laboratory and dried. In the field also, specimens were photographed and their ecological characteristics were noted in order to assist and facilitate taxa identification processes. Furthermore, herbaria specimens were used for mushroom species identification. Both morphological and molecular analyses were used for taxa identification. Photographs of the wild mushroom species were used during interviews and group discussions to enable the informants involved in the study to easily recognize mushroom species in their vicinity. The relative popularity of each medicinal wild mushroom was evaluated based on the informants who independently reported its medicinal use (informant consensus) in the study area.

### *2.4. Data Analysis*

Descriptive statistics were used to present the basic information obtained from the questionnaires. All analyses were conducted based on the number of responses from the informants. A final list of valuable wild mushroom species used by respondents was compiled from the questionnaires and from the field collection data. All fungi were identified at genus and species level whenever possible with the aid of several keys [53–60]. The statistical significance of differences between groups was obtained by performing a chi-square test. Respondents ranked the effect of different threats on a scale of 1 to 3. Thus, a Kruskal–Wallis test was performed to identify the major causes of wild mushroom degradation based on the results of the respondents' views. Clustering was used for the 24 edible species based on their use by local communities. The cluster was based on the average linkage between groups. A binary logistic regression model was used to determine the factors that influence wild mushroom use by households [61]. Data were analyzed using STATISTICA '08 edition software (StatSoft Inc., 1984–2008, Maastricht, the Netherlands).

There are many theoretical perspectives regarding food choice decision, including social behavior, social facts, and social definition theory [61]. Each offers partial insights and makes limiting assumptions that prevents food choice decision variables being fully explained. As a result, we used a food choice process model that was developed based on constructionist social definition perspectives to examine the broadest scope of factors relevant to how individuals constructed their food choice decisions. The model included components of life course, personal food systems and influences. Thus, we selected all our explanatory variables described in Table 2.

**Table 2.** List of variables and variable descriptions used in the binary logistic regression model.

| Variables | Definition | Type of Data |
|---|---|---|
| Region | Administrative area within which the household head lives<br>1. SNNPR<br>2. Amhara | Categorical |
| Woreda | Administrative area within the region in which the household head lives expressed in years of homogeneity in terms of its ethnicity<br>1. Wondo Genet<br>2. Banja<br>3. Fogera | Categorical |
| Age | Age of the household head | Quantitative |
| Educational level | Educational level of the household head:<br>1 = illiterate<br>2 = can read and write<br>3 = primary school completed<br>4 = secondary school completed<br>5 = obtained diploma, degree or above | Categorical |

**Table 2.** *Cont.*

| Variables | Definition | Type of Data |
|---|---|---|
| Ethnicity | Ethnic groups to which the household head belongs—encompasses cultural variations between ethnic groups.<br>1. Sidama<br>2. Agew<br>3. Amhara | Categorical |
| Perceived value | Perception of mushroom consumption for food, income generation, and food security and as a medicine.<br>1. Higher<br>2. Medium<br>3. Low | Categorical |
| Taste experience | Consumption experience of an edible mushroom at least once in his/her lifetime<br>1. Yes<br>2. No | Categorical |
| Nutritional knowledge | Household head's knowledge or lack of knowledge about a mushroom's health-boosting benefits<br>1. I know<br>2. I don't know | Categorical |
| Indigenous identification knowledge | Household head's local knowledge of the identity of edible, poisonous and medicinal wild mushrooms<br>1. Yes<br>2. No | Categorical |

## 3. Results

### *3.1. Ethnotaxa of Wild Mushrooms*

During the forest survey conducted in 2016, our team collected a total of 67 wild mushroom species in the Dry Afromontane forest of the study areas. Of these, 24 species belonging to 19 genera and 9 families were classified as edible. These edible mushrooms were well recognized by the local people when shown photographic images of these species. The fungi are listed in alphabetical order by species name alongside the corresponding indigenous name used by the three ethnic groups (Table 3). The families with the greatest numbers of edible species identified were the Agaricaceae (13 species) and Psathyrellaceae (three species). These two families represented 66.67% of the identified edible wild mushroom species in the study forests, whereas the remaining 33.33% of families were represented by only a single species (Table 3).

The Amhara ethnic group appeared to have limited ethnotaxa knowledge of the wild mushroom species found in the Fogera area. They classified mushrooms as 'Enguday', which in general corresponds to 'fungi' in English. All mushrooms with caps were classified as 'Yejib-tila', which means, "Shadow of the Hyena", which may indicate their cryptic nature (Table 3).

The Sidama ethnic group from the Wondo Genet area was found to be mycophiles and to have a well-developed ethnotaxa for wild mushrooms (Table 3). Some of the names given are associated with attributes of the mushroom species. For example 'Meine' is a name given to a highly valued species that is good to eat due to its taste but scarce due to high levels of collection. 'Gadifuto', which means 'Hyena's fart', is a name given to medicinal mushroom species.

Like the Sidama ethnic group, the Agew from the Banja study area also have a well-developed folk taxonomy for wild mushrooms. 'Wagi', 'Emahoyie pinchina', 'Abahoy pinchina', 'Ye Zinjero Fes', and 'Szantila' are ethnotaxa for some of the wild mushroom species (Table 3). However, for the majority of unrelated taxa, like the Amhara ethnic group, they use the collective name 'Enguday'. Remarkably, the Agew have assigned mushrooms with specific names based on the season in which the mushrooms grow. For example, those mushrooms that grow following the first rain of the season are generally called 'Gunfane', which literally means common cold. The name 'Yejib Tila' is also used by the Agew for all cap fungi.

**Table 3.** Folk taxonomy of collected wild mushroom species used by the Amhara, Agew and Sidama ethnic groups in the study woredas.

| Taxa Name | Family | Local Name of Mushroom Used by Ethnic Group | | | Edibility |
|---|---|---|---|---|---|
| | | Sidama | Agew | Amhara | |
| *Agaricus campestroides* Heinem & Gooss.-Font. | Agaricaceae | Meine/Kakea | Wagi | Enguday | E |
| *Agaricus* $sp_1$. L. | Agaricaceae | | | | |
| *Agaricus* $sp_2$. L. | Agaricaceae | - | - | - | |
| *Agaricus* $sp_3$. L. | Agaricaceae | - | - | - | |
| *Agaricus* $sp_4$. L. | Agaricaceae | - | - | - | |
| *Agaricus* $sp_5$. L. | Agaricaceae | - | - | - | |
| *Agaricus* $sp_6$. L. | Agaricaceae | - | - | - | |
| *Agaricus subedulis* Heinem. | Agaricaceae | Horoqo | Wagi | Enguday | E |
| *Agaricus trisulphuratus* Berk. | Agaricaceae | - | - | - | |
| *Agrocybe pediades* Fayod. | Strophariaceae | Shopenea | Wagi | Enguday | E |
| *Amauroderma regulicolor* Murrill. | Ganodermataceae | - | - | - | |
| *Clitocybe elegans* (Fr.) Staude | Tricholomataceae | Meine | Wagi | Enguday | E |
| *Armillaria* sp. (Fr) Staude. | Physalacriaceae | - | - | - | |
| *Calvatia rubroflava* Fr. | Agaricaceae | Gadifuto | Emahoyie pinchina | Emahoyfese | E |
| *Collybia piperata* (Beeli) Singer. | Tricholomataceae | - | - | - | E |
| *Conocybe* sp. Fayod. | Bolbitiaceae | | | | |
| *Coprinellus domesticus* (Bolton) Vilgalys, Hopple & Jacq. Johnson. | Psathyrellaceae | Feradigamea | Wagi | Enguday | E |
| *Coprinellus* sp. P.Karst. | Psathyrellaceae | - | Wagi | Enguday | E |
| *Coprinopsis nivea* (Pers.) Redhead, Vilgalys & Moncalvo | Psathyrellaceae | Shishonea | Wagi | Enguday | E |
| *Coprinopsis* $sp_1$. P.Karst. | Psathyrellaceae | - | - | - | |
| *Coprinopsis* $sp_2$. P.Karst. | Psathyrellaceae | - | - | - | |
| *Coprinus pseudoplicatilis* Pers. | Psathyrellaceae | Shishonea | Wagi | Enguday | E |
| *Coprinus* sp. Pers. | Agaricaceae | - | - | - | |
| *Crepidotus* sp. (Fr.) Staude. | Crepidotaceae | - | - | - | |
| *Cyptotrama asprata* (Berk.) Redhead & Ginns. | Physalacriaceae | - | - | - | |
| *Favolaschia calocera* R. Heim. | Mycenaceae | - | - | - | |
| *Ganoderma* sp. (Curtis) P.Karst. | Ganodermataceae | Buki bulasa | - | - | E |
| *Gerronema hungo* (Henn.) Degreef & Eyi. | Marasmiaceae | - | - | - | E |
| *Gymnopilus junonius* (Fr.) P.D. Orton. | Cortinariaceae | - | - | - | |
| *Gymnopilus pampeanus* (Speg.) Singer. | Strophariaceae | - | - | - | E |
| *Hygrophoropsis aurantiaca* (Wulfen) Maire. | Hygrophoropsidaceae | Feradigamea | Wagi | Yejib-tila | E |
| *Hymenagaricus fuscobrunneus* Heinem. | Agaricaceae | Qochiqomalea | Szantila | Yejib-tila | E |
| *Hymenagaricus* sp. Heinem. | Agaricaceae | - | - | - | |
| *Hypholoma fasciculare* (Huds.) P. Kumm. | Strophariaceae | - | - | - | |
| *Lepiota cristata* (Bolton) P.Kumm. | Agaricaceae | - | - | - | |
| *Leucoagaricus* sp. Locq. ex Singer | Agaricaceae | Meine | Szantila | Yejib-tila | E |
| *Leucoagaricus leucothites* (Vittad.) Wasser. | Agaricaceae | Kakea | Szantila | Yejib-tila | E |
| *Leucoagaricus rubrotinctus* (Peck) Singer. | Agaricaceae | Kakea | Szantila | Yejib-tila | E |
| *Leucoagaricus* $sp_1$. Locq.ex Singer. | Agaricaceae | Adulla | Szantila | Yejib-tila | E |
| *Leucoagaricus* $sp_2$. Locq.ex Singer | Agaricaceae | Silegaga | Szantila | Yejib-tila | E |
| *Leucocoprinus birnbaumii* (Corda) Singer. | Agaricaceae | Feradigamea | Szantila | Yejib-tila | E |
| *Leucocoprinus cepistipes* (Sowerby) Pat. | Agaricaceae | Feradigamea | Szantila | Yejib-tila | E |
| *Lycoperdon perlatum* Pers. | Agaricaceae | Gadifuto | Abahoy pinchina | Abahoyfese | E |
| *Lycoperdon* sp. Pers. | Agaricaceae | - | - | - | |
| *Marasmius buzungolo* Singer. | Marasmiaceae | - | - | - | |
| *Marasmius katangensis* Singer. | Marasmiaceae | - | - | - | |
| *Marasmius rotalis* Berk & Broome. | Marasmiaceae | - | - | - | |
| *Marasmius* sp. Fr. | Marasmiaceae | - | - | - | |
| *Microporus sp.P.Beauv.* | Polyporaceae | - | - | - | E |
| *Parasola* $sp_1$.Redhead, Vilgalys & Hopple. | Psathyrellaceae | - | - | - | |
| *Parasola* $sp_2$. Redhead, Vilgalys & Hopple. | Psathyrellaceae | - | - | - | |
| *Polyporus badius* (Pers.) Schwein. | Polyporaceae | - | - | - | |
| *Polyporus tuberaster* (Jacq. ex Pers.) Fr. | Polyporaceae | - | - | - | |
| *Psathyrella* $sp_1$. Fr.ex Quél. | Psathyrellaceae | - | - | - | |
| *Psathyrella* $sp_2$. Fr.ex Quél. | Psathyrellaceae | - | - | - | |
| *Psathyrella* $sp_3$. Fr.ex Quél. | Psathyrellaceae | - | - | - | |
| *Psathyrella* $sp_4$. Fr.ex Quél. | Psathyrellaceae | - | - | - | |
| *Psilocybe cyanescens* Wakef. | Hymenogastraceae | - | - | - | |
| *Psilocybe merdaria* (Fr.) Ricken. | Hymenogastraceae | - | - | - | |
| *Psilocybe* sp. (Fr.) P.Kumm. | Hymenogastraceae | - | - | - | |
| *Trametes versicolor* (L.) Lloyd. | Polyporaceae | - | - | - | |
| *Tremella mesenterica* (Schaeff.) Retz. | Tremellaceae | - | - | - | |
| Un described $sp_1$. | Undescribed | - | - | - | |
| Un described $sp_2$. | Undescribed | - | - | - | |
| Un described $sp_3$. | Undescribed | - | - | - | |
| Un described $sp_4$. | Undescribed | - | - | - | |
| *Xerula* sp. Maire. | Physalacriaceae | - | - | - | |

Note: E = edibility.

## 3.2. *Wild Mushroom Collection and Habitat Type*

Based on the respondents' answers, the three ethnic groups differed significantly in their knowledge of wild mushroom habitats (chi-square test; $p < 0.05$). Overall, six different habitat types were distinguished by respondents. However, the home garden and swampy areas are far less relevant for the Amhara and Agew ethnic groups than other habitats (Figure 2). Compared with Sidama respondents, a significantly greater proportion of respondents belonging to the Amhara and Agew ethnic groups considered the natural forest to be the main mushroom habitat (Agew–Sidama = 0.001 and Amhara–Sidama = 0.001) (Figure 2). By contrast, a significantly greater proportion of Sidama respondents considered grazing areas to be a mushroom habitat compared with the Amhara and Agew respondents ($p > 0.05$). However, the proportion of Sidama and Agew respondents that considered plantations and agricultural lands to be habitats for wild mushroom species was not significantly different (Figure 2; $p > 0.05$).

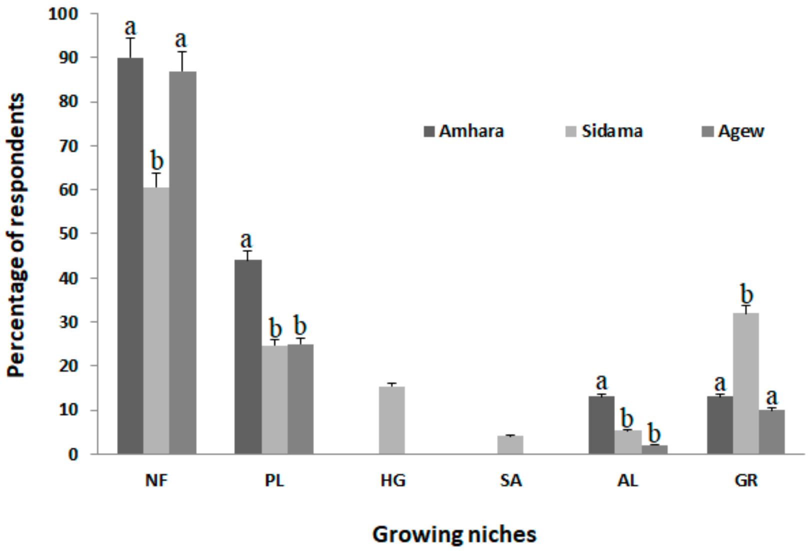


**Figure 2.** Perceptions of individuals in the three ethnic groups interviewed in the study areas about wild mushroom habitats. The data shown are mean results ± the standard error amount by five percent of the mean. Within each habitat type, values with the same letter above the bar are not significantly different. Abbreviations: NF, natural forest; PL, plantation forest; HG, home garden; SA, swampy area; AL, agricultural land; and GR, grazing area. Note: wild mushroom species are found in more than one habitat type; thus, the total percentage for all habitats is >100%.

We found significant differences in the awareness and use of wild mushroom species (chi-square test; $p < 0.05$) among the three ethnic groups. From the household survey, we realized that the Sidama ethnic group was more familiar with mushrooms than the Amhara and Agew ($p < 0.05$), whereas the Amhara and Agew were not significantly different from each other in terms of their awareness and use of wild mushroom species ($p > 0.05$).

The household interview revealed that the Sidama ethnic group collects wild mushroom species for food (93%) and medicinal (7%) purposes. About 63% of the respondents indicated that they usually collect wild mushrooms, 25% indicated that they occasionally collect wild mushroom species and 12% not collected mushrooms. The Sidama collect fungal species that have different nutritional modes. Saprotrophic fungi are preferred as food (90%) compared with other fungal types whereas *Ganoderma*, *Calvatia* and *Lycoperdon* (Table 4) are the three most commonly gathered genera for medicinal purposes. When dried, the spores of these mushroom species can be spread on skin to heal wounds and skin disease (Table 4).

Wild mushroom collection is common practice among the Sidama community: in most cases, children (22%) and women (70%) are the main collectors. This is because children are responsible for livestock keeping in the field and women are responsible for collecting firewood from the forests in the Wondo Genet area. Moreover, during the focus group discussions, the Sidama groups reported that the women in their communities know where and when wild mushroom species will be at their best. However, in some cases, men also collect mushrooms when they unintentionally find them as they walk to or from the forest. According to the group discussion, medicinal mushroom species are usually collected by traditional herbalists; thus herbalists in the study areas are key for determining the ethnotaxa of medicinal species.

**Table 4.** Traditional use and preparation of the twelve most listed wild mushroom species by the Amhara, Agew and Sidama ethnic groups in the study areas.

| Species Scientific Name | Traditional Uses and Preparation | | | |
|---|---|---|---|---|
| | Amhara | Agew | Sidama | Local Preparation |
| *Agaricus campestroides* Heinem & Gooss.-Font. | NK | NK | F | Cooked with vegetables, oil and chili sauce |
| *Agaricus subedulis* Heinem. | NK | NK | F | Cooked with vegetables, oil and chili sauce |
| *Clitocybe elegans* (Fr.) Staude | NK | NK | F | Cooked with vegetables, oil and chili sauce |
| *Calvatia rubroflava* Fr. | NK | NK | F&M | Cooked with vegetables and oil. Also, spores/powder used to treat wounds |
| *Hymenagaricus fuscobrunneus* Heinem. | NK | NK | F | Cooked with vegetables, oil and chili sauce |
| *Leucoagaricus* sp. Locq. ex Singer | NK | NK | F | Cooked with vegetables and oil |
| *Leucoagaricus leucothites* (Vittad.) Wasser. | NK | NK | F | Cooked with vegetables and oil |
| *Leucoagaricus rubrotinctus* (Peck) Singer. | NK | NK | F | Cooked with vegetables and oil |
| *Leucoagaricus* sp$_1$. Locq.ex Singer. | NK | NK | F | Cooked with vegetables and oil |
| *Leucoagaricus* sp$_2$. Locq.ex Singer | NK | NK | F | Cooked with vegetables and oil |
| *Lycoperdon perlatum* Pers. | NK | F | F&M | Roasted or cooked with vegetables and oil Also, spores/powder used to treat skin infection and wounds of both human and livestock |
| *Ganoderma* sp. (Curtis) P.Karst. | NK | NK | M | Medicinal for stomachaches and to treat wounds |

**Note:** F, species used for food; NK, species not known as food or medicine; and M, species used for medicine.

Although none of the Amhara and Agew respondents collect wild mushrooms for food or medicinal purposes, about 57% and 72% of the Amhara and Agew respondents, respectively, indicated that they do have some knowledge of the medicinal and food use value of wild mushrooms. They obtained this information from different sources as from forefathers (Amhara, 23%; Agew, 43%), elderly people belonging to other ethnic groups (Gumze) in their vicinity (Amhara, 34%; Agew, 46%), friends (Amhara, 10%; Agew, 43%), forestry expertise (Amhara, 12%; Agew, 33%), and NGOs (Amhara, 4%; Agew, 11%).

### 3.3. *Seasonality/Phenology of Mushrooms*

The seasonality of wild mushroom appearance was not significantly different among the three study areas (chi-square test; $p > 0.05$; Figure 3). In all three cases, wild mushroom species develop during the short (peak in March) and long (peak in July) rainy seasons (Figure 3), suggesting the importance of rainfall patterns in fungal phenology.

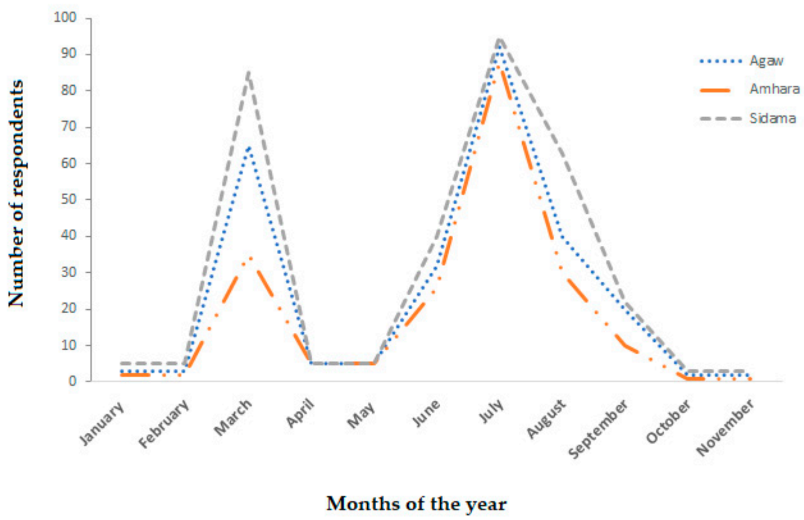


**Figure 3.** Phenology of mushrooms perceived by the three ethnic groups in the study area.

The Sidama collect wild mushroom species in Wondo Genet during the long rainy season (June to September). Mushroom availability in this area peaks between mid-July and the end of August (Figure 3). Interestingly, the majority of the respondents (97%) from Wondo Genet suggested that edible mushrooms grew during this season in well-known places and that the timing and pattern of their appearance was predictable. However, there were a few respondents (3%) from this study area who believed that some species could also be found during the dry season.

### 3.4. Wild Mushroom Use and Consumption

The identified valuable wild mushroom species clustered in three different groups and one independent species when analyzed based on their use as food, medicine, food and medicine and unknown use (Figure 4). The respondents indicated that 12 species were not known for their use by the locals. In the second group, nine wild mushroom species were identified as edible species that were consumed by locals (Figure 4). In the third group, *Calvatia rubroflava* and *Lycoperdon perlatum* were used as food and medicine. The *Ganoderma* species, which was classified as an independent species, was used for medicinal purposes only.

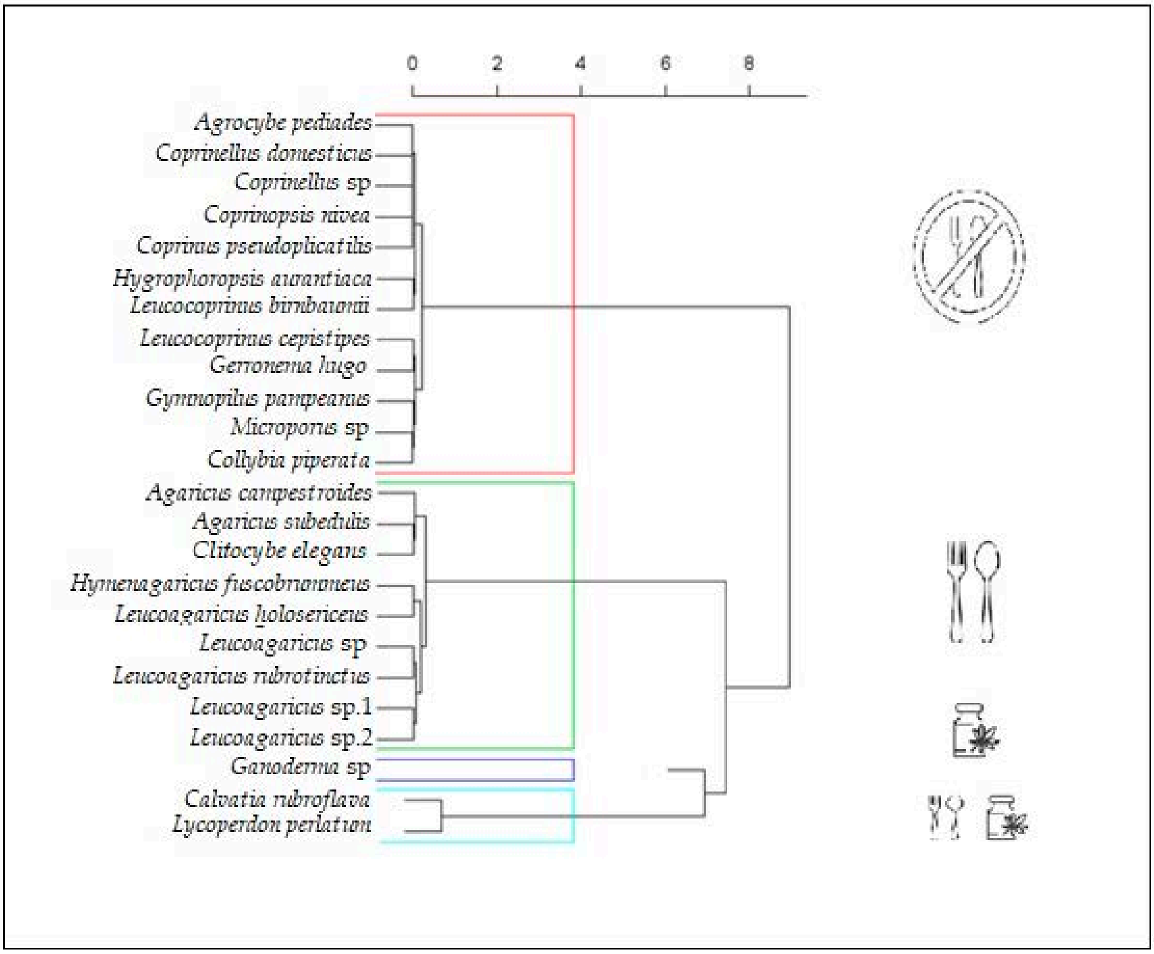


**Figure 4.** Dendrogram showing the classification of edible wild mushroom species based on their use by local communities. The horizontal axis represents the distance or dissimilarity between clusters and the vertical axis represents the species and clusters.

Wild mushroom use and consumption patterns varied among the three study areas (chi-square test; $p < 0.05$), with only the Sidama ethnic group using wild mushrooms. However, among the Sidama respondents, there was a significant difference in their perception of wild mushroom species (chi-square test; $p < 0.001$). About 86.7% of the interviewed individuals considered mushrooms to be a substitute for meat, whereas 21.3% considered mushrooms to be a vegetable in their daily meal. The majority of the respondents consumed mushrooms by cooking them with onions, vegetables, and oil; however, some (23%) consumed mushrooms when cooked with chili sauce or when cooked with oil and salt (8%) (Table 4).

About 71% of the Sidama that were interviewed were able to distinguish between edible and poisonous wild mushrooms. Edible species were distinguished based on aroma (like that of the soil), color (usually gray), the size of the sporocarps, habitat (leaf litter) and edibility information acquired from their forefathers. Moreover, the Sidama believe that if animals feed on a mushroom species then the mushroom must be edible. The most commonly used edible species in the Wondo Genet area included *Agaricus subedulis* Heinem., *Hymenagaricus fuscobrunneus* Heinem., *Clitocybe elegans* (Fr.) Staude., *Lycoperdon perlatum* Pers., *Calvatia rubroflava* Fr., and *Leucoagaricus leucothites* (Vittad.) Wasser. The Sidama do not preserve wild mushroom species for future use because they do not have the knowhow for mushroom preservation.

The Sidama identified poisonous mushrooms by their bright colors. In addition, if, for example, a dead insect is found on a mushroom or skin itch when the mushroom touches the body, then the mushroom is considered to be poisonous. If poisoned by ingesting a mushroom in Wondo Genet, the individuals interviewed indicated that they would drink fresh goat's blood (95%), the juice of *Kocho*, which is produced from *Ensete ventricosum* (Welw.), milk (90%), or vomit (65%). Moreover, 87% of the interviewed individuals indicated that '*Gadifuto*' (both *C. rubroflava* and *L. perlatum*) were used as a powder/spores to cure skin disease and to treat human and livestock wounds.

Although wild mushroom collection by the Amhara and the Agew ethnic groups is not common practice, the group discussions in both study areas revealed that the local people were aware that mushrooms are a food resource because their descendants and neighboring communities (mainly the Gumz) used to collect and eat mushrooms from the forest. Interestingly, some Agew individuals (3%) used to eat roasted mushrooms, and they indicated that this tradition was inherited from their forefathers. People participating in the group discussion in the Banja Woreda also confirmed that their ancestors used to eat roasted and cooked young *Lycoperdon* species with vegetables and oil. Among the interviewed individuals from both ethnic groups, 91% considered the majority of wild mushroom species to be poisonous and not good for health. However, no cases of mushroom poisoning have been recorded in the Banja or Fogera study areas. Interestingly, some members of both groups (Amhara (16%) and Agew (21%)) have some knowledge of cultivated edible mushrooms and their nutritional value (i.e., *Agaricus bisporus* (J.E.Lange) Imbach, *Lentinula edodes* (Berk.) Pegler, and *Pleurotus ostreatus* (Jacq. ex Fr.) P.Kumm) because they have received training from Woreda forestry expertise.

Wild mushroom species have not been commercialized in any of the study areas. The entire mushroom harvest in Wondo Genet is used for household consumption.

### *3.5. Factors Influencing Wild Mushroom Use*

According to the binary logistic model, most of the evaluated factors differed significantly in their influence on wild mushroom consumption (chi-Square, $p < 0.05$; model fit, $R^2 = 0.883$). Only age, nutritional knowledge, and indigenous identification knowledge had no influence on consumption ($p > 0.05$; Table 5). The positive elasticity in the coefficients implies that a unit addition to any of the significant parameters will have a positive influence on wild mushroom consumption by the studied ethnic groups. This also holds true for the negative significant estimated coefficients. A unit reduction to any of them will have a negative influence on wild mushroom consumption by the studied ethnic groups

**Table 5.** Factors influencing wild mushroom consumption based on a binary logistic regression model.

| Parameters | Coefficients | Standard Error | *p*-Value |
|---|---|---|---|
| Region | 0.43 | 0.51 | 0.000 ** |
| Woredas | 5.52 | 0.58 | 0.000 ** |
| Age | −0.03 | 0.02 | 0.889 |
| Education level | −1.41 | 1.05 | 0.000 ** |
| Ethnicity | 9.24 | 1.10 | 0.000 ** |
| Perceived value | −5.64 | 0.42 | 0.004 * |
| Taste experience | 7.02 | 0.65 | 0.003 * |
| Nutritional knowledge | −17.83 | 0.49 | 0.078 |
| Indigenous identification knowledge | −0.26 | 0.22 | 0.122 * |
| Constant | 0.88 | 0.34 | 0.290 |

**Note:** ** and * indicate significance at the 0.01 and 0.05 probability level, respectively.

### 3.6. Perceived Status and Threats

According to the perceived view of the respondents, the status of wild mushroom species did not differ significantly among the three ethnic groups (chi-square test; $p > 0.05$). The perception of the status of wild mushroom species was decreasing in their locality was decreasing (Figure 5). The aggregate perception also indicated that 60.67% of respondents perceived that the status of wild mushroom species had decreased compared with that in previous years, 32% perceived the status to be unchanged and 7.33% perceived the status to have increased.

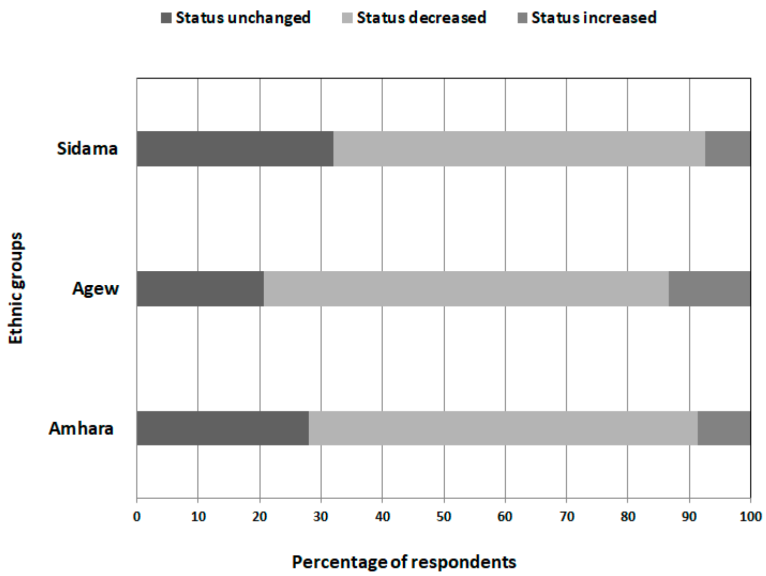


**Figure 5.** Perceived view of respondents in the Amhara, Agew and Sidama ethnic groups regarding the status of wild mushroom species in their locality.

Based on the results of the respondents' views, the major causes of wild mushroom degradation were perceived to be free grazing, agricultural expansion, settlements, fire incidence, climate change, and unknown reasons (Table 6). Among these, free grazing, agricultural expansion, settlements, and fire incidence were perceived to have a significant influence (Kruskal–Wallis test, $p < 0.05$) on the status of wild mushroom species in the three study areas.

**Table 6.** Major causes of wild mushroom degradation based on the mean risk value for each threat categorized by respondents from each ethnic group on a scale of 1 to 3. Threat: Ag, agricultural land expansion; Set, settlements; F, fire incidence in the forest; G, free grazing; CC: climate change; and UF, unknown factors.

| Ethnic Group | Ag | Set | F | G | CC | UF |
|---|---|---|---|---|---|---|
| Amhara | 2.58 | 1.74 | 2.99 | 2.22 | 1.00 | 1.00 |
| Agew | 1.85 | 1.11 | 2.24 | 1.18 | 1.00 | 1.00 |
| Sidama | 2.46 | 1.44 | 2.28 | 2.08 | 1.00 | 1.00 |
| Total mean | 2.34 | 1.43 | 2.45 | 1.90 | 1.00 | 1.00 |
| Std. deviation | 0.71 | 0.50 | 0.50 | 0.86 | 0.00 | 0.00 |
| Kruskal–Wallis test ($p$ value) | 0.000 | 0.008 | 0.000 | 0.000 | 1.00 | 1.00 |

## 4. Discussion

Previous Ethiopian ethnomycological reports have usually been based on small-scale case studies [33,34,37,62]. In this ethnomycological study, we included two regions with different ethnic compositions. The Sidama ethnic group are mycophiles and have a more extensive folk taxonomy for mushrooms than the other ethnic groups [14,27,63], indicating that the Sidama ethnic group is good at sharing ethnomycological knowledge within the ethnic group [27,29,63]. Traditional healers are key informants for the identification and characterization of medicinal species because they use different species for their traditional medicinal practices [31,62]. In addition to their use as food, *Lycoperdon perlatum* Pers. and *Calvatia rubroflava* Fr. were reported to be the most useful and important medicinal wild mushroom species because they play a key role in treating wounds and skin disease. Interestingly, *Laetiporus sulphureus* (Bull.) Murrill. sensu lato has also been reported to be a common traditional medicine for lessening pain during childbirth in Kaffa areas in the southern part of Ethiopia [36], where local people preserve powder of this species for long periods in the house. Interestingly, in this study, a *Ganoderma* species was also used for medicinal purposes by the local people. Other studies have also reported that these mushrooms are used in traditional medicine by different local communities around the world to treat stress, pain, measles and lung diseases [64–66].

In our study, the surveys revealed that the Amhara and the Agew have limited ethnomycological knowledge and do not eat mushrooms even though their parents or grandparents have consumed wild mushroom species in the past and commercial mushroom species are being cultivated artificially in their locality. The non-consumption of mushrooms will eventually represent a loss of mycological knowledge in these ethnic groups [29]. Only two of the species common to their locality have been assigned a folk taxonomy by these ethnic groups (Table 3) while the common name of the majority of wild mushroom species was reported to be Enguday or Yejibtila. Therefore, rigorous work is needed in Banja and Fogera to develop a folk taxonomy [31,39]. However, this study did provide us with an opportunity to understand how different ethnic groups in Ethiopia use their ethnomycological knowledge. This sentiment echoes expressed by Tuno [34], who reported that observing the traditional ways of mushroom utilization by the Majangir ethnic group in the southwest part of Ethiopia provided a unique opportunity for studying how people belonging to traditional tribes in Africa utilize mushroom as foods [34,39]. The findings presented in [34] suggested that communities in rural part of Ethiopia are familiar with wild mushroom species growing in their locality and prize them as subsidiary food items collected in the forest [34].

In this study, communities, particularly the Sidama, were easily able to distinguish between wild mushroom species using their own traditional protocols. Broadly, they used morphological characters, smell and habitat to identify edible mushrooms. These criteria are in line with [31,34]. The oldest accounts of this practice among tribes in developing countries have been putatively reflected by different authors [67–70]. Beside these criteria, in rural areas of Ethiopia, the local people also use the presence or absence of a strong bad smell [34] to determine the edibility of mushrooms. Thus, it could be assumed that such traditional protocols are the product of ancient experimentations and possibly opportunistic discoveries by the indigenous people despite the confounded genealogy of their cultural uses [63]. Among the Sidama, women are generally involved in the collection and gathering of wild mushroom species and children are involved in the collection of well-known mushrooms. This is in line with [36], who reported that women are often responsible for this type of activity in the south and southwestern parts of the country, and also agrees with the findings of several other authors [27,34,39,63]. Because women are responsible for collecting firewood from the forests in the Wondo Genet area, they have become expert at distinguishing between edible and poisonous mushrooms [34,36] and are knowledgeable about the spatial distribution of mushrooms in terms of habitat and associated substrates in the forest and other niches [31,38].

Respondents also revealed that all mushrooms are collected during the rainy season (June to September) and used especially during food shortage periods. However, Dejene et al. [31] reported that the collection of some species, such as *Laetiporus* sp., could occur during the dry season [34,37]. Grain is the principal source of nutrition for communities in most parts of the country. In general, the availability of mushrooms in the rainy season coincides with periods of grain scarcity, suggesting that local communities may use wild mushroom species together with other edible wild foods during this period as a gap filler [31]. Common areas identified for wild mushroom collection were natural forests, farmlands, grazing lands, home gardens, and swampy areas. Most of these ecological niches are quite similar to those reported by [36,37] in the south and south western parts of the country. If communities are trained well, this culture of collecting wild mushroom species could be expanded to shift from subsistence use to income-generating small-scale business speculations through their commodification.

We have got determinant variables on wild mushroom consumption by the local communities in the three study woredas, implying that any of the significant variables has a positive effect on wild mushroom use the local people. For example, "taste experience" has a positive effect on wild mushroom use in the study area. This implies that those individuals who have tasted a wild mushroom species have better awareness of its use than those that have not tasted the species. This experience helps to understand the local livelihood context, the sources and nature of risks and the coping behavior of communities. This supports the findings of Lemenih et al. [71] who indicated that household experience is a commonly applied strategy for coping with shocks and is instrumental in poverty reduction. Thus, a local communities' experience of tasting a mushroom has implications for poverty reduction through emphasizing local available sources of the mushroom, enabling rural households to diversify their food sources. The same applied to the other positive coefficient variables, implying that a unit addition to any one of them will have a positive implication for wild mushroom consumption.

We evaluated different threats that affect wild mushroom species based on the perceived causes for degradation. Many of the threats related to habitat degradation are affecting wild mushroom species in Ethiopia in general. Free grazing and agricultural land expansion were considered to be the main threats in this study. This might be because rapidly growing human and livestock populations are driving an ever-increasing demand for crop and grazing land, which is aggravating the degradation of habitats in Ethiopia [32,72,73]. Such anthropogenic pressures are likely to also have an impact on useful known and unknown wild mushroom species, some of which could face extinction [73]. Moreover, this loss also limits the benefits that can be obtained from wild mushroom components of forest resources as well as the ethnomycological knowledge of different ethnic groups associated with mushroom use. Thus, the sustainable management of Ethiopian forest systems is mandatory in order to play major roles in the conservation and development of wild edible and medicinal mushrooms that cannot be economically cultivated, require very specific habitats, and are exceptionally difficult to reproduce in nurseries or laboratories. Furthermore, the importance of fungal resources has recently been brought to the forefront due to their ecological and economic importance. There have been many efforts to record their diversity at local and regional scales. Thus, product diversification is a fundamental strategy to integrate a model of sustainable forest exploitation and reverse the degradation of wild mushroom species through promoting ecosystem services such as biodiversity conservation.

## 5. Conclusions

This study has attempted to provide baseline information about the ethnomycology of three ethnic groups in Ethiopia. The Amhara and Agew ethnic groups are located in the same geographic region, are in contact with the same natural resources and have a similar knowledge of wild mushrooms. This similarity is a result of their cultural exchanges, coexistence, and shared historical events. Furthermore, parallel responses were reported in many cases, such as the consumption of wild mushroom species by their parents or grandparents even though the respondents do not eat mushrooms, which will eventually lead to the loss of mycological knowledge in these two ethnic groups. By contrast, wild mushroom consumption is an integral part of the cultural knowledge of seasonal resources among the Sidama communities in the southern part of the country. Thus, the different traditional food composition and recipes of the ethnic group should be further studied to ensure the potential value of wild mushroom species in the nutrition and food security role in the community.

Sidama women are primarily responsible for gathering and collecting valuable wild mushrooms, indicating that gender is one of the variables that influence the local knowledge of wild mushroom use and their distribution in the locality. This could also have implications for women contributing toward household food security using locally available food resources such as fungi. In other words, fungi could be a means of providing supplementary food, thereby reducing poverty and providing opportunities for women living in unfavorable areas and, hence, reducing inequality. Similarly, although most of the individuals interviewed from the Amhara and Agew ethnic groups were not familiar with the wild mushrooms, they appreciated the food value of the mushrooms when they tasted them. Thus, the experience of tasting mushrooms by local communities has implications for poverty reduction through emphasizing local available sources that enable rural households to diversify their food sources.

Although we have tried to document the traditional knowledge and uses of wild mushroom species of three ethnic groups in Ethiopia, more studies are needed to ensure that much of the potential value of wild mushroom species and the ethnomycology knowledge of local communities is not lost. Such knowledge is part of the identity of these communities: knowledge of wild mushroom uses, linguistics, and harvesting can prevent their loss as modernization proceeds due to the dominance of hegemonic culture. Documentation of this knowledge could promote a revaluation of wild mushroom species as resources and promote their conservation. The knowledge and nomenclature of useful species could also be revitalized, and their use encouraged, and in doing so, wild mushroom species could make a greater contribution to food security, especially in a country like Ethiopia where food security is a country-wide issue.

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## References

1. Godfray, H.C.; Crute, I.; Haddad, L.; Lawrence, D.; Muir, J.; Nisbett, N.; Pretty, P.; Robinson, S.; Toulmin, C.; Whiteley, R. The future of the global food system. *Philos. Trans. R. Soc. B* **2010**, *365*, 2769–2777. [CrossRef] [PubMed]
2. Pinstrup-Andersen, P. Food security: Definition and measurement. *Food Secur.* **2009**, *1*, 5–7. [CrossRef]
3. De Caluwé, E.; Halamová, K.; Van Damme, P. *Adansonia digitata* L.—A review of traditional uses, phytochemistry and pharmacology. *Afr. Focus* **2010**, *23*, 10–51. [CrossRef]

4. Termote, C.; Bwama Meyi, M.; Dhed'a Djailo, B.; Huybregts, L.; Lachat, C.; Kolsteren, P.; Van Damme, P. A biodiverse rich environment does not contribute to a better diet: A case study from DR Congo. *PLoS ONE* **2012**, *7*, e30533. [CrossRef]
5. Fentahun, M.T.; Hager, H. Exploiting locally available resources for food and nutritional security enhancement: Wild fruits diversity, potential and state of exploitation in the Amhara region of Ethiopia. *Food Secur.* **2009**, *1*, 207–219. [CrossRef]
6. Mengistu, F.; Hager, H. Wild edible fruit species cultural domain, informant species competence and preference in three districts of Amhara region, Ethiopia. *Ethnobot. Res. Appl.* **2008**, *6*, 487–502. [CrossRef]
7. DeClerck, F.; Fanzo, J.; Palm, C.; Remans, R. Ecological approaches to human nutrition. *Food Nutr. Bull.* **2011**, *32*, S41–S50. [CrossRef]
8. Powell, B.; Thilsted, S.H.; Ickowitz, A.; Termote, C.; Sunderland, T.; Herforth, A. Improving diets with wild and cultivated biodiversity from across the landscape. *Food Secur.* **2015**, *7*, 535–554. [CrossRef]
9. Rowland, D.; Blackie, R.R.; Powell, B.; Djoudi, H.; Vergles, E.; Vinceti, B.; Ickowitz, A. Direct contributions of dry forests to nutrition: A review. *Int. For. Rev.* **2015**, *17*, 45–53. [CrossRef]
10. Ickowitz, A.; Rowland, D.; Powell, B.; Salim, M.A.; Sunderland, T. Forests, trees, and micronutrient-rich food consumption in Indonesia. *PLoS ONE* **2016**, *11*, e154139. [CrossRef]
11. Johnson, K.; Jacob, A.; Brown, M. Forest cover associated with improved child health and nutrition: Evidence from the Malawi Demographic and Health Survey and satellite data. *Glob. Health Sci. Pract.* **2013**, *1*, 237–248. [CrossRef] [PubMed]
12. Cai, M.; Pettenella, D.; Vidale, E. Income generation from wild mushrooms in marginal rural areas. *For. Policy Econ.* **2011**, *13*, 221–226. [CrossRef]
13. Sarma, T.; Sarma, I.; Patiri, B. Wild edible mushrooms used by some ethnic tribes of Western Assam. *Bioscan* **2010**, *3*, 613–625. [CrossRef]
14. Boa, E. *Wild Edible Fungi: A Global Overview of Their Use and Importance to People*; Non-Wood Forest Products No. 17; FAO: Rome, Italy, 2004; p. 147.
15. Chang, Y.S.; Lee, S.S. Utilisation of macrofungi species in Malaysia. *Fungal Divers.* **2004**, *15*, 15–22.
16. Ferreira, I.C.F.R.; Vaz, J.A.; Vasconcelos, M.H.; Martins, A. Compounds from wild mushrooms with antitumor potential. *Anticancer Agents Med. Chem.* **2010**, *10*, 424–436. [CrossRef]
17. Gryzenhout, M.; Roets, F.; de Villiers, R. Fungal conservation in Africa. *Mycol. Balc.* **2010**, *7*, 43–48.
18. Marconi, S.; Durazzo, A.; Camilli, E.; Lisciani, S.; Gabrielli, P.; Aguzzi, A.; Gambelli, L.; Lucarini, M.; Marletta, L. Food composition databases: Considerations about complex food matrices. *Foods* **2018**, *7*, 2. [CrossRef]
19. Durazzo, A.; Lisciani, S.; Camilli, E.; Gabrielli, P.; Marconi, S.; Gambelli, L.; Aguzzi, A.; Lucarini, M.; Maiani, G.; Casale, G.; et al. Nutritional composition and antioxidant properties of traditional Italian dishes. *Food Chem.* **2017**, *218*, 70–77. [CrossRef]
20. Wani, B.; Bodha, R.; Wani, A. Nutritional and medicinal importance of mushrooms. *J. Med. Plants Res.* **2010**, *4*, 2598–2604.
21. Bano, Z.; Shasirekha, M.; Rajarathnam, S. Improvement of the bioconversion and biotransformation efficiencies of the oyster mushroom (*Pleurotus sajor-caju*) by supplementation of its rice straw with oil seed cakes. *Enzym. Microb. Technol.* **1993**, *15*, 985–989. [CrossRef]
22. Mattila, P.; Könkö, K.; Eurola, M.; Pihlava, J.M.; Astola, J.; Vahteristo, L.; Hietaniemi, V.; Kumpulainen, J.; Valtonen, M.; Piironen, V. Contents of vitamins, mineral elements, and some phenolic compounds in cultivated mushrooms. *J. Agric. Food Chem.* **2001**, *49*, 2343–2348. [CrossRef] [PubMed]
23. Kakon, A.; Choudhury, M.B.K.; Saha, S. Mushroom Is an Ideal Food Supplement. *J. Dhaka Natl. Med. Coll. Hosp.* **2012**, *18*, 58–62. [CrossRef]
24. Dejene, T.; Agamy, S.; Agúndez, D.; Martín-Pinto, P. Ethnobotanical survey of wild edible fruit tree species in lowland areas of Ethiopia. *Forests* **2020**, *11*, 177. [CrossRef]
25. Garibay-Orijel, R.; Caballero, J.; Estrada-Torres, A.; Cifuentes, J. Understanding cultural significance, the edible mushrooms case. *J. Ethnobiol. Ethnomed.* **2007**, *3*, 4. [CrossRef] [PubMed]
26. Härkönen, M.; Niemelä, T.; Mbindo, K.; Kotiranta, H.; Pierce, G.D. Zambian mushrooms and mycology. *Norrlinia* **2015**, *29*, 1–5.
27. Tibuhwa, D. Folk taxonomy and use of mushrooms in communities around Ngorongoro and Serengeti National Park, Tanzania. *J. Ethnobiol. Ethnomed.* **2012**, *8*, 36. [CrossRef] [PubMed]

28. Héritier, M.; Hippolyte, N.; Cephas, M.; Hoffman, B.; Gallaher, T. Importance indices in ethnobotany. *Ethnobot. Res. Appl.* **2007**, *5*, 201–218.
29. Kamalebo, H.M.; Nshimba, H.; Wa, S.; Ndabaga, C.M. Uses and importance of wild fungi: Traditional knowledge from the Tshopo province in the Democratic Republic of the Congo. *J. Ethnobiol. Ethnomed.* **2018**, *14*, 13. [CrossRef]
30. Asfaw, Z.; Tadesse, M. Prospects for sustainable use and development of wild food plants in Ethiopia. *Econ. Bot.* **2001**, *55*, 47–62. [CrossRef]
31. Dejene, T.; Oria-de-Rueda, J.A.; Martín-Pinto, P. Wild mushrooms in Ethiopia: A review and synthesis for future perspective. *For. Syst.* **2017**, *26*, eR04. [CrossRef]
32. Lulekal, E.; Asfaw, Z.; Kelbessa, E.; Van Damme, P. Wild edible plants in Ethiopia: A review on their potential to combat food insecurity. *Afr. Focus* **2011**, *24*, 71–121. [CrossRef]
33. Semwal, K.C.; Lemma, H.; Dhyani, A.; Equar, G.; Amhare, S. Mushroom: Nature's treasure in Ethiopia. *Momona Ethiop. J. Sci.* **2014**, *6*, 138–147. [CrossRef]
34. Tuno, N. Mushroom utilization by the Majangir, an Ethiopian tribe. *Mycologist* **2001**, *15*, 78–79. [CrossRef]
35. Awas, T.; Asfaw, Z.; Nordal, I.; Demissew, S. Ethnobotany of Berta and Gumuz people in western Ethiopia. *Biodiversity* **2010**, *11*, 45–53. [CrossRef]
36. Abate, D. Wild mushrooms and mushroom cultivation efforts in Ethiopia. *WSMBMP Bull.* **2014**, *11*, 1–3.
37. Muleta, D.; Woyessa, D.; Teferi, Y. Mushroom consumption habits of Wacha Kebele residents, southwestern Ethiopia. *Glob. Res. J. Agric. Biol. Sci.* **2013**, *4*, 6–16.
38. Dejene, T.; Oria-de-Rueda, J.A.; Martín-Pinto, P. Edible wild mushrooms of Ethiopia: Neglected non-timber forest products. *Rev. Fitotec. Mex.* **2017**, *40*, 391–397. [CrossRef]
39. Dejene, T.; Oria-de-Rueda, J.A.; Martín-Pinto, P. Fungal community succession and sporocarp production following fire occurrence in Dry Afromontane forests of Ethiopia. *For. Ecol. Manag.* **2017**, *398*, 37–47. [CrossRef]
40. Beza, Z.B. Challenges and prospects of community based ecotourism development in Lake Zengena and its environs, North West Ethiopia. *Afr. J. Hosp. Tour. Leis.* **2017**, *6*, 1–12.
41. Friis, B.; Demissew, S.; Breugel, P. *Atlas of the Potential Vegetation of Ethiopia*; The Royal Danish Academy of Sciences and Letters: Copenhagen, Denmark, 2010; p. 307.
42. Kebede, M.; Kanninen, M.; Yirdaw, E.; Lemenih, M. Vegetation structural characteristics and topographic factors in the remnant moist Afromontane forest of Wondo Genet, south central Ethiopia. *J. For. Res.* **2013**, *24*, 419–430. [CrossRef]
43. Takele, A. Analysis of Rice Profitability and Marketing Chain: The Case of Fogera Woreda South Gondar Zone, Amhara National Regional State, Ethiopia: ILRI-IPMS. Available online: https://agris.fao.org/agris-search/search.do?recordID=QT2016102236 (accessed on 19 December 2019).
44. Eshete, A. The Frankincense Tree of Ethiopia: Ecology, Productivity and Population Dynamics. Ph.D. Thesis, Wageningen University, Wageningen, The Netherlands, 2011. Available online: https://www.wur.nl/en/show/The-frankincense-tree-of-Ethiopia-ecology-productivity-and-population-dynamics.htm (accessed on 17 June 2020).
45. Wassie, A.; Teketay, D.; Powell, N. Church forests in North Gonder administrative zone, Northern Ethiopia. *For. Trees Livelihoods* **2005**, *15*, 349–373. [CrossRef]
46. Kassa, H.; Campbell, B.; Sandewall, M.; Kebede, M.; Tesfaye, Y.; Dessie, G.; Seifu, A.; Tadesse, M.; Garedew, E.; Sandewall, K. Building future scenarios and uncovering persisting challenges of participatory forest management in Chilimo Forest, Central Ethiopia. *J. Environ. Manag.* **2009**, *90*, 1004–1013. [CrossRef] [PubMed]
47. Shumi, G. The Structure and Regeneration Status of Tree and Shrub Species of Chilimo Forest Ecological Sustainability Indicators for Participatory Forest Management (PFM) in Oromia, Ethiopia. Available online: https://agris.fao.org/agris-search/search.do?recordID=ET2008000082 (accessed on 17 June 2020).
48. Mekonnen, Z.; Kassa, H.; Woldeamanuel, T.; Asfaw, Z. Analysis of observed and perceived climate 623 change and variability in Arsi Negele District, Ethiopia. *Environ. Dev. Sustain.* **2018**, *20*, 1191–1212. [CrossRef]
49. Bernard, H. *Research Methods in Anthropology: Qualitative and Quantitative Approaches*, 4th ed.; AltaMira Press: New York, NY, USA, 2006; 824p.
50. Bowen, G.A. Naturalistic inquiry and the saturation concept: A research note. *Qual. Res.* **2008**, *8*, 137–152. [CrossRef]

51. Guest, G.; Bunce, A.; Johnson, L. How Many Interviews Are Enough? *Field Methods* **2006**, *18*, 59–82. [CrossRef]
52. Martin, G.J. *Ethnobotany: A Methods Manual*; Chapman & Hall: London, UK, 1995; 268p.
53. Antonín, V. *Flora of Tropical Africa, Volume 1: Monograph of Marasmius, Gloiocephala, Palaeocephala and Setulipes in Tropical Africa*; National Botanic Garden: Meise, Belgium, 2007; 177p.
54. Hama, O.; Maes, E.; Guissou, M.; Ibrahim, D.; Barrage, M.; Parra, L.; Raspe, O.; De Kesel, A. *Agaricus subsaharianus*, une nouvelle espèce comestible et consomméeau Niger, au Burkina Faso et en Tanzanie. *Crypto. Mycol.* **2010**, *31*, 221–234.
55. Heinemann, P. *Champignons Récoltés au Congo Belge*; Botanic Garden Meise: Meise, Belgium, 1956; Volume 5, pp. 99–119.
56. Morris, B. An annotated check-list of the macrofungi of Malawi. *Kirkia* **1990**, *13*, 323–364.
57. Pegler, D.; Rayner, R. A contribution to the Agaric flora of Kenya. *Kew Bull.* **1969**, *23*, 347–412. [CrossRef]
58. Rammeloo, J.; Walleyn, R. The edible fungi of Africa south of the Sahara: A literature survey. *Scr. Bot. Belg.* **1993**, *5*, 1–62.
59. Ryvarden, L.; Piearce, G.D.; Masuka, A.J. *An Introduction to the Larger Fungi of South Central Africa*; Baobab Books: Harare, Zimbabwe, 1994; Available online: https://agris.fao.org/agris-search/search.do?recordID=XF2016048164 (accessed on 17 June 2020).
60. Singer, R. Marasmius. In *Flore Iconographique des Champignons du Congo*; National Botanic Garden of Belgium: Meise, Belgium, 1965; Volume 14, pp. 253–278.
61. Gujarati, D. *Essentials of Econometrics*, 4th ed.; McGraw-Hill: New York, NY, USA, 1992; 54p.
62. Osarenkhoe, O.O.; John, O.A.; Theophilus, D.A. Ethnomycological conspectus of West African mushrooms: An awareness document. *Adv. Microbiol.* **2014**, *4*, 39–54. [CrossRef]
63. Ekandjo, L.K.; Chimwamurombe, P.M. Traditional medicinal uses and natural hosts of the genus *Ganoderma* in north-eastern parts of Namibia. *J. Pure Appl. Microbiol.* **2012**, *6*, 1139–1146.
64. Kadhila-Muandingi, N.P. The Distribution, Genetic Diversity, and Uses of Ganoderma Mushrooms in Oshana and Ohangwena Regions of Northern Namibia. Master's Thesis, University of Namibia, Windhoek, Namibia, 2010. Available online: http://repository.unam.edu.na/handle/11070/525 (accessed on 17 June 2020).
65. Sun, S.; Gao, W.; Lin, S.; Zhu, J.; Xie, B.; Lin, Z. Analysis of genetic diversity in Ganoderma population with a novel molecular marker SRAP. *Appl. Microbiol. Biotechnol.* **2006**, *72*, 537–543. [CrossRef] [PubMed]
66. Adhikari, M.K.; Devkota, S.; Tiwari, R.D. Ethnomycolgical knowledge on uses of wild mushrooms in western and central Nepal. *Our Nat.* **2005**, *3*, 13–19. [CrossRef]
67. Borah, N.; Semwal, R.L.; Garkoti, S.C. Ethnomycological knowledge of three indigenous communities of Assam, India. *Indian J. Tradit. Knowl.* **2018**, *17*, 327–335.
68. Kinge, T.R.; Apalah, N.A.; Nji, T.M.; Acha, A.N.; Mih, A.M. Species richness and traditional knowledge of macrofungi (mushrooms) in the Awing Forest Reserve and communities, Northwest Region, Cameroon. *J. Mycol.* **2017**, *2017*, 2809239.
69. Tibuhwa, D.D. Termitomyces species from Tanzania, their cultural properties and unequalled basidiospores. *J. Biol. Life Sci.* **2012**, *3*, 140–159. [CrossRef]
70. Ongoche, I.C.; Otieno, D.J.; Oluoch-Kosura, W. Assessment of factors influencing smallholder farmers' adoption of mushroom for livelihood diversification in Western Kenya. *Afr. J. Agric. Res.* **2017**, *12*, 2461–2467. [CrossRef]
71. Lemenih, M.; Olsson, M.; Karltun, E. Comparison of soil attributes under *Cupressus lusitanica* and *Eucalyptus saligna* established on abandoned farmlands with continuously cropped farmlands and natural forest in Ethiopia. *For. Ecol. Manag.* **2004**, *195*, 57–67. [CrossRef]
72. Giday, M.; Asfaw, Z.; Woldu, Z. Medicinal plants of the Meinit ethnic group of Ethiopia: An ethnobotanical study. *J. Ethnopharmacol.* **2009**, *124*, 513–521. [CrossRef]
73. Lemenih, M.; Kassa, H. Re-greening Ethiopia: History, challenges and lessons. *Forests* **2014**, *5*, 1896–1909. [CrossRef]

Original article - II

# Impacto del uso de la tierra en la estructura del rodal y el rendimiento de frutos de *Tamarindus indica* L. en las tierras secas del sureste de Etiopía

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## Resumen

En este estudio, evaluamos el estado del rodal, las variables dendrométricas y la producción de frutos de árboles de tamarindo (*Tamarindus indica* L.) que crecen en zonas naturales matorralizadas y complementariamente en tierras agrícolas en áreas de tierras secas de Etiopía. El estudio de la vegetación se realizó utilizando el método de un cuarto central. También se evaluó el rendimiento de frutos de 54 árboles. Se estimó la densidad de árboles y la producción de frutos por ha. Hubo una diferencia significativa en la densidad de árboles de tamarindo entre los dos tipos de uso de la tierra ($p = 0.01$). La producción media de frutos de los árboles de las tierras de cultivo fue significativamente mayor que el de los árboles de los matorrales. Sin embargo, el tamarindo tiene una estructura insostenible en las tierras de cultivo. También se observaron diferencias en las características dendrométricas de los árboles entre los dos tipos de uso de la tierra. Se seleccionaron modelos predictivos para las estimaciones de producción de frutos de tamarindo en ambos tipos de uso de la tierra. Aunque la mayoría de los árboles de las tierras agrícolas produjeron <5000 frutos al año-1, la selección de germoplasma de tamarindo en sus áreas de distribución naturales podría mejorar la producción. Así, se requiere el desarrollo de planes de manejo para establecer rodales que tengan una estructura de diámetros más equilibrada y así asegurar la continuidad de la población y las producciones de frutos en esta zona, particularmente en los campos de cultivo. Esta información de referencia podría ayudar en otros lugares en áreas que enfrentan desafíos similares para la especie debido al cambio de uso de la tierra.

Palabras claves: *Matorrales; dendrométrico; tierras de cultivo; árbol frutal indígena; estado de la población; fruta silvestre*

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# Land-Use Impact on Stand Structure and Fruit Yield of *Tamarindus indica* L. in the Drylands of Southeastern Ethiopia

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**Abstract:** In this study, we evaluated stand status, dendrometric variables, and fruit production of Tamarind (*Tamarindus indica* L.) trees growing in bushland and farmland-use types in dryland areas of Ethiopia. The vegetation survey was conducted using the point-centered quarter method. The fruit yield of 54 trees was also evaluated. Tree density and fruit production in ha were estimated. There was a significant difference in Tamarind tree density between the two land-use types ($p$ = 0.01). The mean fruit yield of farmland trees was significantly higher than that of bushland trees. However, Tamarind has unsustainable structure on farmlands. Differences in the dendrometric characteristics of trees were also observed between the two land-use types. Predictive models were selected for Tamarind fruit yield estimations in both land-use types. Although the majority of farmland trees produced <5000 fruit year$^{-1}$, the selection of Tamarind germplasm in its natural ranges could improve production. Thus, the development of management plans to establish stands that have a more balanced diameter structure and thereby ensure continuity of the population and fruit yields is required in this area, particularly in the farmlands. This baseline information could assist elsewhere in areas that are facing similar challenges for the species due to land-use change.

**Keywords:** bushland; characteristics; dendrometric; farmland; indigenous fruit tree; population status; wild fruit

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## 1. Introduction

The wide array of altitudinal gradients and the varying topographic features of Ethiopia have created quite diverse ecological conditions, each with their own characteristic flora and fauna [1]. Approximately 55% of Ethiopian land is arid to semi-arid [2] and, hence, drylands are one of the major agro-ecological zones found in this country [2,3]. In these areas, people depend heavily on natural resources [4,5], and on services provided by ecosystems and agro-ecological systems [2]. Indeed, the majority of the people derive their livelihood from agriculture combined with extensive livestock breeding and the use of a variety of natural products [3]. Among these services, non-timber forest products (NTFPs) play a vital role [6]. In total, 88 valuable species producing NTFPs have been recorded in the dryland forests of Ethiopia [6]. If they are managed wisely, NTFPs can provide a sustainable stream of income and subsistence products while supporting other economic activities via the provision of ecosystem services [7].

*Tamarindus indica* L. (family Fabaceae) is an indigenous NTFP-producing tree species that is found in sub-Saharan Africa [8–10]. In Ethiopia, Tamarind are found in *Combretum–Terminalia* and *Acacia–Commiphora* woodlands vegetation types [8]. Tamarind has an ecological and economic significance [11]. Ecologically, it is important because it can grow well under a wide range of soil and climatic conditions and, hence, is found in semi-arid areas, low-altitude wooded grassland, savannah, and bushlands [11] and also found along streams and riverbanks [8]. Tamarind can also grow at altitudes ranging from 0 to

1500 m above sea level (m asl) with an annual temperature range of 20–33 °C and annual precipitation range of 350–2700 mm [8]. The extensive root system of the Tamarind tree contributes to its resistance to drought and wind. Thus, Tamarind is potentially suitable for future reforestation or restoration of moisture-deficient arid and semiarid areas [12]. Economically, Tamarind is important because its fruit has a wide range of domestic and industrial uses [13]. In Ethiopia, the fruit is used for food and medicinal purposes by local communities [14]. In addition, rural people sell Tamarind fruit in local markets to generate income to supplement the household economy [15].

Despite the benefits that can be derived from the management and proper conservation of Tamarind trees, the progressive forest land-use change, particularly the conversion of forest lands to agricultural fields of crops in dryland areas of Ethiopia, has imposed pressure on Tamarind trees [6,14]. This land-use change has had a serious impact on the Tamarind tree population, because it depends on natural regeneration [16]. Furthermore, the available information generally lacks adequate quantitative analysis for the development of economic opportunities based on local resources such as Tamarind trees as an alternative to excessive import of exotic products [17]. Although some studies have been undertaken to investigate the fruit, morphological characteristics, and use of Tamarind in different localities in Ethiopia [14,16], the species is still inadequately characterized. Thus, studying how land-use influences the population structure of Tamarind trees might help us to develop effective conservation strategies in accordance with the needs of the local population. In particular, a better understanding of Tamarind dimensional structure could be used as the basis for strong management decisions if this is combined with information about the species spatial distribution [18], patterns of use and harvesting [19,20]. Furthermore, given the contribution of Tamarind fruit to the livelihoods of rural people in Ethiopia, an evaluation of potential yields and important tree parameters that influence fruit production are imperative to enable further improvement and management of this tree.

In this study, we assessed the population patterns and dendrometric characteristics of Tamarind trees growing on farmland and bushland-use types in the Dello Menna district, Bale zone, Southeastern Ethiopia. We hypothesized that land-use type affects the density and population pattern of Tamarind trees in the studied district. In this sense, as this species provides a highly appreciated fruit, the farmers try to conserve some Tamarind trees to cover this demand. Thus, our expectation was to find a higher number of these largest-size Tamarind trees in farmlands when comparing with bushlands due to the lack of competence with other bushes and trees. In addition, we expected to find a gap between regeneration and midterm-size trees, since the seedlings are frequently removed after the rainy period when the farmers prepare the soil for new cultivation. We also hypothesized that the dendrometric characteristics such as crown structure and number of branches of Tamarind trees would vary between the two land uses and, in turn, that such variation would have an impact on the fruit yield of Tamarind trees. Thus, the specific aims of this study were to assess the stand status of *T. indica*, fruit production and dendrometric variables by comparing the farmland and bushland-use types. The information generated from this study provides baseline information that can be used to promote the conservation and sustainable use of Tamarind trees and other valuable wild edible tree species under different land-use types in Ethiopia and could also assist other countries with valuable wild trees that are facing similar issues due to land-use change.

## 2. Materials and Methods

### 2.1. Description of the Study Area

The study was conducted in the Dello Menna district (between 5°53′ N and 6°27′ N and between 39°15′ E and 40°38′ E) in the Bale zone of Oromia regional state, Southeastern Ethiopia (Figure 1). Dello Menna is 800 to 2000 m asl and characterized by bimodal rainfall. The main rainy season occurs from early March until the end of June, followed by a shorter rainy season from late September until the end of November. Therefore, there are five dry months in this area: i.e., January, February, July, August, and December. The mean annual rainfall is 986 mm, and the mean annual temperature is 22.3 °C. The average annual rainfall and temperature of the study area during the year (2019) of data collection were 1113.67 mm and 21.26 °C, respectively, indicating that the rainfall amount was good during this period of time. The study area has a plain topography with a few areas of rugged and mountainous terrain. Nitisol is the dominant soil type in this area [21], ranging from a reddish-brown clay toward the higher altitudes and tending to form a reddish-orange sandy soil toward the lower altitudes. Rocky outcrops are prevalent along streams and steeply sloping hills. The inhabitants of the area are primarily Oromo. They practice a mixed farming system involving livestock and subsistence agriculture, which is the main livelihood of the rural community [22]. Coffee, bananas, and papayas are the main perennial cash crops. Teff, sorghum, and maize are the main annual crops cultivated by farmers.

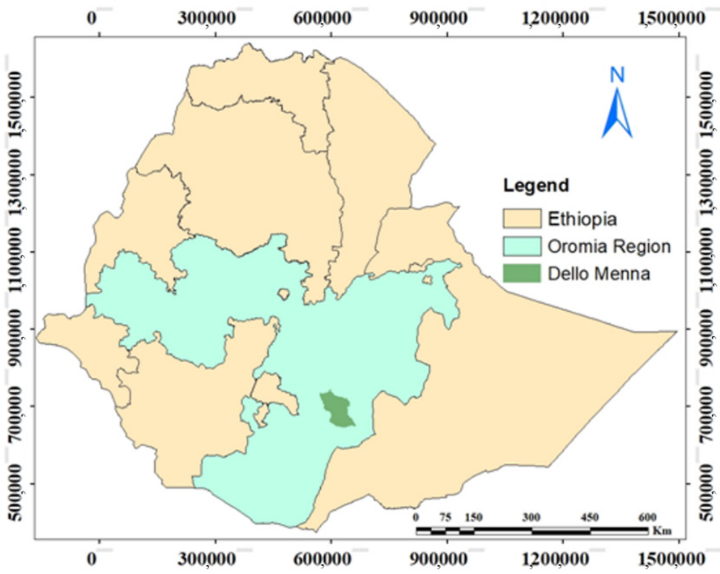


**Figure 1.** Map showing the location of the study area, the Dello Menna district, in the Oromia region of Southeastern Ethiopia.

### 2.2. *Vegetation Inventory and Data Collection*

Woody vegetation characteristics, such as species composition, density, and size structure, were measured by placing transects across the two major land-use types in the study district, namely farmland and bushlands in 2019. For this purpose, we used the point-centered quarter (PCQ) method, a "plot-less" sampling technique, at points along transects across the sampled areas [23]. The transect direction was determined randomly by selecting a bearing from the center of each land-use system, with another transect perpendicular to the first transect (i.e., two cross-cutting transects at 90 degrees). A series of points 100 m apart were systematically located along each transect. A total of 25 and 29 sampling points were used for farmland and bushland-use types, respectively. At every sampling point, four quadrants (90 degrees) were created using the transect line and a line perpendicular to it. The measurement and recording of species in each quadrant was carried out in two stages. Firstly, the *T. indica* that was closest to the sampling point in each of the four quadrants was selected (all sizes were sampled, i.e., seedlings, and mature trees) and then its distance from the central point was recorded. Tree diameters above the basal swell were also measured. Secondly, any woody plant species closest to the sampling point within each of the four quadrants were selected, and the distance from the central point and the tree diameter was recorded. The names of all species registered in the quadrants were noted to determine the species composition.

### *2.3. Fruit Yield Estimation*

The productivity of each Tamarind tree in terms of fruit yield was measured using the harvesting method described by Sundriyal and Sundriyal [24]. In total, 27 individual fruit-producing Tamarind trees in each land-use type were randomly selected [25]. The total number of branches and the number of fruit-bearing branches were also recorded during the fruit-harvesting period, as described by Cunningham [25]. To obtain an accurate record of the number of fruit produced per tree, Tamarind fruit were counted when fully matured [26] (i.e., when pods had turned from green to brown) but before the fruit had fallen or been eaten by wild animals. The number of fruit on each terminal branch was determined by either standing on the ground to count fruit hanging down below the canopy, or by climbing the tree to count those in the canopy, or by using a ladder to count those at the top of the crown. Fruit numbers and their weight were recorded for each terminal branch separately and summed for each branch and then the total for each tree obtained by summation. In addition, tree dendrometric variables such as height, diameter at breast height (DBH), crown diameter, and number of branches were recorded [27]. Crown surface area, crown volume, and crown depth were estimated using the measurements obtained for the other dendrometric variables. The DBH was measured using a diameter tape and total height was measured using a Suunto Clinometer. The crown diameter was measured using a cross-method, where the length of the longest spread from edge to edge across the crown and the longest spread perpendicular to the first cross-section through the central mass of the crown were measured. The crown diameter is the average of these two lengths. The number of branches on each tree was also counted in the field.

### *2.4. Data Analysis*

To assess the impact of land use on the Tamarind tree species, we compared variables relating to population structure, dendrometric characteristics, and fruit yield. Data analyses were performed using Statistical Package for Social Sciences (SPSS) version 23. Data were log-transformed when needed to achieve the parametric criteria of normality and homoscedasticity necessary for analysis of variance. Differences between the two land-use types for the different variables were evaluated using one-way analysis of variance (ANOVA). The relationship between fruit yield and individual tree attributes was determined through multinomial classification model approach. The models were fitted to the responses to predict the probabilities of the different possible outcomes of fruit yield categories [28]. The analysis used total fruit yield categories as a dependent variable, whereas combinations of dendrometric characteristics were used as explanatory variables. We grouped the response variables as tree size (DBH, height), crown structure (crown diameter, crown depth, crown surface and crown volume) and tree branches (number of branches). For each dependent variable, fruit yield was divided into yield categories (very low, low, high and very high yield) [29]. Then, we combined all the possible combinations, and as a result, we compared the Akaike Information Criterion (AIC) values to select the most suitable model for each studied system. For a given data set, the smaller the AIC, the better the model [30]. Once we obtained the best variable combinations, the model allowed us to predict the probability of the fruit yield for a particular multinomial discrete categorical choice. Coefficients of each model were used to estimate the fruit yield categories of Tamarind trees.

The Crown Surface Area (CSA) estimated using the formula CSA = $2\pi rh$ and Crown Volume (CVol) estimated using the formula CVol = $2/3\ (\pi r^2 h)$, where $\pi = 3.14$, r = crown radius and h = the crown depth, which is calculated from the lower side of the crown from tree height. This is now included in the text of the methodology part and the change is highlighted in the text. The crown depth is a parameter used to calculate the crown volume and surface area of individual trees by subtracting the height to the lower side of the crown from tree height.

The population structure of Tamarind trees in both land-use types was assessed by analyzing size class diameters using tree density data collected from PCQ [23,31]. Five diameter classes were used in this assessment: seedlings (recently regenerated); 1 to 10 cm; 11 to 20 cm; 21 to 30 cm; and >30 cm.

i. Determination of total distances between trees and sampling points.
ii. The average distance of the sampled tree from the point, d, was calculated.
iii. The mean area was determined using the formula mean area = $(d)^2$.
iv. The absolute density of all tree species (trees per ha) was calculated: absolute density = mean area/10,000 $m^2$.
v. The formulas Fa = Na/n and Fr = (Fa/ΣFai)*100% were used to determine the absolute and relative frequency, respectively, where:
   - Fa is the absolute frequency of the target species;
   - Na is the number of points where at least one individual species occurs;
   - n is the total number of sampling points;
   - Fr is the relative frequency of the target species; and
   - ΣFai is the sum of absolute frequencies of all the species in a transect.
vi. The relative density of Tamarind was determined by dividing the total number of Tamarind trees by the total number of trees and is expressed as a percentage [23].

## 3. Results

### *3.1. Species Composition, Densities, and Stand Structure*

In total, 16 woody tree species belonging to nine families and 12 genera were recorded during the survey of the study area (Table 1). The most prevalent families were the Fabaceae (five species), followed by the Combretaceae (three species), and Malvaceae (two species). These three families represented 53% of the recorded trees, whereas the remaining 47% of families were represented by only a single tree (Table 1). In addition to *T. indica*, *Dobera glabra* was also identified on farmland as an edible fruit tree that was utilized by local communities in the study area. When considering all the trees recorded in each of the land-use types, we found significant differences in the diameter class distribution ($p < 0.05$; Figure 2A). Significantly more trees in the 1–10 cm and 11–20 cm diameter classes were found in bushland than on farmland. However, significantly more regeneration (i.e., seedlings) ($p = 0.02$) and trees with a diameter greater than 30 cm were found on farmland than in bushland ($p = 0.035$; Figure 2A). The total population status of all the trees recorded for the two land-use types is shown in Figure 2A.

Analysis of the *T. indica* population revealed that a significantly greater number of mature Tamarind trees were recorded in bushland than on farmland (F = 10.59, $p = 0.01$; Figure 2B; Table 1). However, a significantly greater number of Tamarind trees with a DBH of >30 cm (F = 1.69, $p = 0.046$) and more regeneration (F = 7.21, $p = 0.021$) was observed on farmland than in bushland. The average DBH of trees on farmland was 58.78 ± 23.71 cm and seedling density was 15.81 ± 2.04 seedlings per ha (Figure 2B). However, no Tamarind trees in the 1–10 cm, 11–20 cm, and 21–30 cm diameter classes were recorded on farmland (Figure 2B). There was no significant difference in Tamarind tree height ($p > 0.05$) between the two land-use types. The total population status of *T. indica* trees for the two land-use types is shown in Figure 2B.

**Table 1.** Densities of woody tree species growing on farmland and bushland in the study area in Dello Menna, Southeastern Ethiopia.

| Species | Family | Density (Trees ha$^{-1}$) | |
|---|---|---|---|
| | | Farmland | Bushland |
| *Acacia etbaica* Schweinf. | Fabaceae | 3.95 ± 0.012 | 2.00 ± 0.001 |
| *Acacia mellifera* (M. Vahl) Bentham | Fabaceae | – | 1.55 ± 0.010 |
| *Acacia senegal* Willd. | Fabaceae | 3.95 ± 0.012 | 10.82 ± 0.024 |
| *Acacia tortilis* (Forssk.) Hayne | Fabaceae | 98.79 ± 0.095 | 26.27 ± 0.024 |
| *Carissa edulis* (Edgew.) Benth. | Apocynaceae | – | 1.54 ± 0.007 |
| *Combretum molle* R.Br. ex G.Don | Combretaceae | – | 2.00 ± 0.010 |
| *Commiphora baluensis* Jacq. | Combretaceae | – | 26.27 ± 0.07 |
| *Dobera glabra* (Forssk.) Juss. ex Poir. | Salvadoraceae | 15.81 ± 0.035 | 7.73 ± 0.011 |
| *Euclea racemosa* L. | Ebenaceae | – | 1.55 ± 0.007 |
| *Grewia bicolor* Juss. | Malvaceae | – | 1.55 ± 0.001 |
| *Grewia villosa* Willd. | Malvaceae | – | 1.54 ± 0.007 |
| *Lannea schimperi* (A. Rich.) Engl. | Anacardiaceae | – | 3.09 ± 0.008 |
| *Ochna inermis* (Forssk.) Schweinf | Ochnaceae | – | 1.55 ± 0.005 |
| *Tamarindus indica* L. | Fabaceae | 23.71 ± 0.050 | 35.54 ± 0.049 |
| *Terminalia polycarpa* Engl. & Diels | Combretaceae | – | 1.56 ± 0.001 |

Note: the number of stems per hectare includes both mature trees and regenerated seedlings. Values shown are means ± standard deviation.

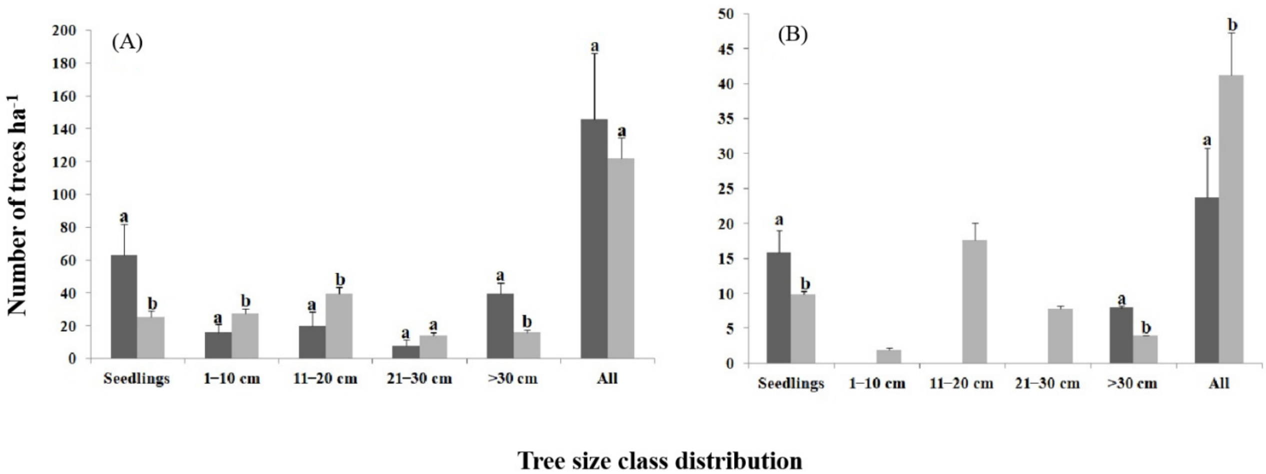


**Figure 2.** Size class distribution (based on diameter at breast height, DBH) of all tree species (**A**), and of the *Tamarindus indica* tree (**B**) on farmland (dark-gray bars) and in bushland (light-gray) in Dello Menna, Southeastern Ethiopia. Error bars indicate the standard deviation of the mean. Values with the same letter within each size class are not significantly different.

### *3.2. Tamarind Fruit Yield and Dendrometric Variables*

There was a significant difference in Tamarind fruit yield and dendrometric variables between the two land-use types (Table 2). Estimated variables such as number of fruit, fruit yield per tree, DBH, and crown diameter of *Tamarind* were significantly higher for trees on farmland than in bushland ($p < 0.05$) (Table 2). Unlike this, the height and slender ration were greater for the bushland-use type (Table 2). A greater number of fruit were obtained from trees on farmland than in bushland, with a mean value of 4343 on farmland, ranging from 1485 to 8569 fruit per Tamarind tree, and an estimated mean annual yield of 537.05 kg. The mean number of fruit from trees in bushland was 2537, ranging from 1500 to 3500 fruit per tree. The individual fruits weight did not show significant differences ($p > 0.05$) between the two land-use types (Table 2).

**Table 2.** Dendrometric variables (± standard deviation) of *Tamarindus indica* trees for two land-use types in the study area, Dello Menna district, Southeastern Ethiopia.

| Tree Characteristic | Land-Use | | *F*-Value | *p*-Value |
|---|---|---|---|---|
| | Farmland | Bushland | | |
| Diameter (cm) | 52.22 ± 8.43 | 30.56 ± 13.31 | 51.08 | 0.0000 |
| Height (m) | 9.78 ± 1.78 | 16.30 ± 5.13 | 38.82 | 0.0002 |
| Tree slender ration | 0.23±0.12 | 0.95 ± 0.36 | 93.28 | 0.0000 |
| Crown diameter (m) | 10.26 ± 1.48 | 4.18 ± 0.93 | 4.02 | 0.0000 |
| Number of fruit per tree | 4343 ± 1996 | 2537.04 ± 615.13 | 20.17 | 0.0001 |
| Individual fruits weight (g) | 26.02 ± 1.19 | 22.74 ± 6.21 | 1.57 | 0.2158 |
| Fruit yield (kg) per tree | 537.05 ± 255.16 | 172.81 ± 62.82 | 51.78 | 0.0000 |

When correlating variables with Tamarind fruit yield, we found strong correlations between fruit yield and variables such as the number of fruit (0.94) and the number of branches (0.54) ($p$ < 0.01; Figure 3A) for trees growing in bushland. A moderate correlation of yield and crown diameter (0.40) was also observed among trees growing in bushland (Figure 3A). The correlation of crown volume, crown surface area, and DBH with Tamarind total yield was weak for trees growing in bushland (Figure 3A). However, there was a strong correlation between fruit yield and variables such as number of fruit (0.80) and fruit yield (0.67) for trees growing on farmland ($p$ < 0.001; Figure 3B). A moderate correlation (0.45) was also observed between fruit yield and the number of branches ($p$ < 0.05; Figure 3B). Details of correlations between different dendrometric and production variables for Tamarind trees growing on the two land-use types are shown in Figure 3.

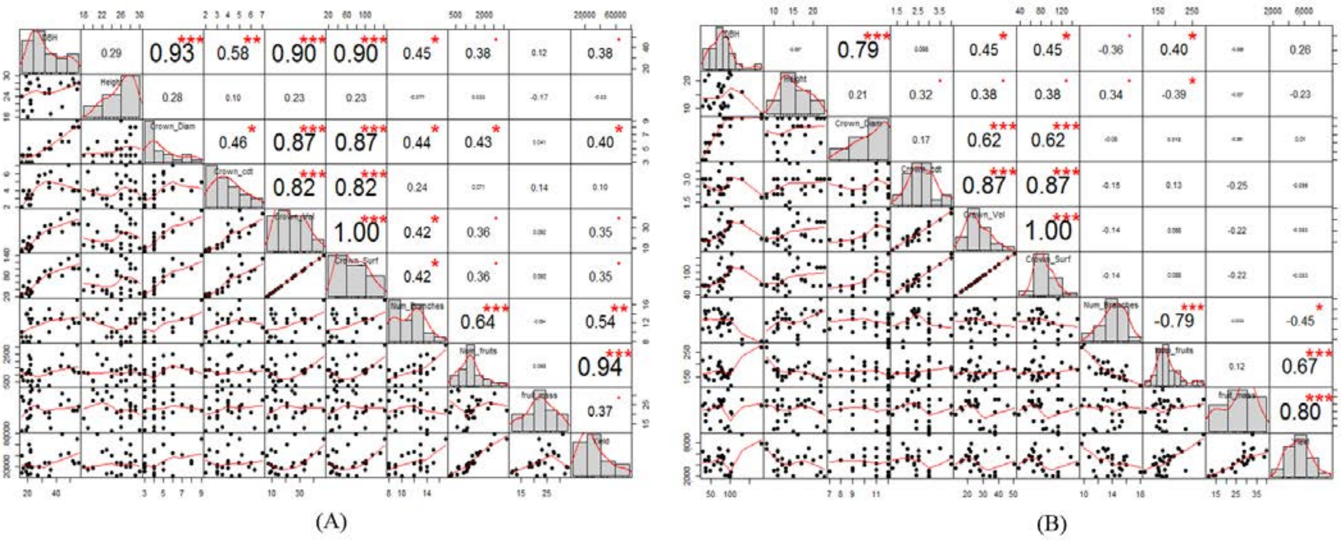

**Figure 3.** Scatter plot matrices showing correlation coefficients between tree variables and significance levels for Tamarind trees growing in bushland (**A**) and on farmland (**B**) in the Dello Menna district, Southeastern Ethiopia. Abbreviations: DBH, diameter at breast height; Crown_diam, crown diameter; Crown_cdt, crown depth; Crown_vol, crown volume; Crown_surf, crown surface area; Num_branches, number of branches; Num_fruits, number of fruit. On the bottom of the diagonal, bi-variate scatter plots with a fitted line are displayed. On the top of the diagonal, the value of the correlation is shown, plus the significance level of the $p$-values, which are indicated by red asterisks. $p$-values: ***, <0.001; **, <0.01; and *, <0.05.

### 3.3. Prediction Models to Estimate Fruit Yield of Tamarind

Different dendrometric parameters from the tree size, crown dimensions and tree branches groups were used to fit the model in order to predict the Tamarind fruit yields from the farmland and bushland-use types (Table 3). The dendrometric parameters identified as best from each group were tested in different combinations (16 combinations) to identify the best classification model that included one tree parameter from each group to predict the fruit yield (Table 3).

**Table 3.** Combination of results fitted multinomial classificatory models to fruit yield of *Tamarindus indica* trees for two land-use types in the study area, the Dello Menna district, Southeastern Ethiopia.

| Land-Use Type | Tree Size | | Crown Dimensions | | | | Tree Branches | AIC |
|---|---|---|---|---|---|---|---|---|
| | DBH | Height | Crown Diameter | Crown Depth | Cvol | CSA | NB | |
| Farmland | 1 | | 1 | | | | 1 | 60.30 |
| Farmland | 1 | | | 1 | | | 1 | 57.18 |
| Farmland | 1 | | | | 1 | | 1 | 57.17 |
| Farmland | 1 | | | | | 1 | 1 | 57.17 |
| Farmland | | 1 | 1 | | | | 1 | 59.56 |
| Farmland | | 1 | | 1 | | | 1 | 63.18 |
| Farmland | | 1 | | | 1 | | 1 | 62.45 |
| Farmland | | 1 | | | | 1 | 1 | 62.29 |
| Bushland | 1 | | 1 | | | | 1 | 87.74 |
| Bushland | 1 | | | 1 | | | 1 | 88.80 |
| Bushland | 1 | | | | 1 | | 1 | 88.66 |
| Bushland | 1 | | | | | 1 | 1 | 88.62 |
| Bushland | | 1 | 1 | | | | 1 | 88.73 |
| Bushland | | 1 | | 1 | | | 1 | 88.98 |
| Bushland | | 1 | | | 1 | | 1 | 89.19 |
| Bushland | | 1 | | | | 1 | 1 | 89.19 |

Note: DBH: diameter at breast height, Cvol: crown volume; CSA: crown surface area, NB: number of branches and AIC: Akaike Information Criterion.

Four classificatory models (Table 4), three from the farmland-use type and one from the bushland-use type, were selected to predict the fruit yield based on their AIC values (Table 3). The parameters from each group (tree size, crown dimensions, and tree branches) were tested in different combinations to identify the best model that potentially included one tree parameter from each group (Table 4). DBH, crown diameter, crown volume, crown surface area and number of branches were used to predict Tamarind fruit yield from the farmland-use type models, while DBH, crown diameter and number of branches were used for bushland-use type model. In the farmland-use type models, the sign of the coefficients were positive in all of the three fruit yield potential categories (high, low and very high), which indicates that, as the number of parameters increases, total Tamarind fruit yield also increases. Thus, the average fruit yield would increase for every 1 unit increase in the number of tree parameters used in the models for Tamarind trees growing in farmlands of the study area.

**Table 4.** *Tamarindus indica* fruit yield production (kg ha$^{-1}$) multinomial classificatory models based on yield category for the two land-use types in the study area, Dello Menna district, Southeastern Ethiopia.

| Model | Land Uses | Yield Category | Intercept | Tree Size | | Crown Dimensions | | | | Nbr |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | DBH | H | Cdr | Cdt | Cvol | CSA | |
| 1 | Farmland | High | 41.6988 | −0.4059 | - | - | 3.4148 | - | - | −0.9906 |
| | | low | 31.0819 | −0.4160 | - | - | 4.5007 | - | - | −0.4235 |
| | | Very high | 0.7668 | 0.5824 | - | - | −2.5525 | - | - | −5.5457 |
| 2 | Farmland | High | 39.2695 | −0.3716 | - | - | - | 0.2177 | - | −0.8997 |
| | | low | 30.0463 | −0.4041 | - | - | - | 0.3275 | - | −0.3404 |
| | | Very high | 1.8206 | 1.2428 | - | - | - | −2.7251 | - | −4.6551 |
| 3 | Farmland | High | 38.8419 | −0.3674 | - | - | - | - | 0.0714 | −0.8877 |
| | | low | 29.6071 | −0.4000 | - | - | - | - | 0.1080 | −0.3276 |
| | | Very high | 1.2811 | 0.8070 | - | - | - | - | −0.2852 | −5.1273 |
| 4 | Bushland | High | −2.1487 | 0.0053 | - | 0.3524 | - | - | - | −0.0777 |
| | | low | 2.4140 | 0.1327 | - | −0.9756 | - | - | - | −0.1184 |
| | | Very high | −3.0593 | 0.0837 | - | −0.6959 | - | - | - | 0.2844 |

Note: DBH: Diameter at breast height, H: height, Cdr: crown diameter, Cdt: crown depth, Cvol: crown volume, CSA: crown surface area and Nbr: number of branches.

## 4. Discussion

To sustainably use and conserve the forest, we need to identify the potential species present and analyze their stand status and production potential, including harvesting level [32]. In this study, a total of 16 woody tree species were associated with the two land-use types studied. Fabaceae was the most dominant family, which is similar to the findings of other studies in the same area [33,34]. This may imply that the environmental conditions in this area are more favorable for species belonging to this family than to other families [34]. The analysis also confirmed that land use impacts woody vegetation, particularly the distribution of *T. indica* in the study area. The density of Tamarind trees was much higher in bushland than in farmland. However, large trees were predominantly growing on farmland, which supports previous findings by Djossa et al. [35], who reported that trees growing on farmland were significantly larger but lower in density than in bushland. This might be because agricultural areas are still farmed in fairly traditional ways and, thus, the overall tree density is low because of regular cropping [36]. However, the condition of these old trees will likely have long-term consequences for the continuity of trees on farmlands, specifically Tamarind trees, and in the long-run, may even lead to population collapse. Thus, the establishment of management plans to create stands that have a more balanced age structure and, thereby, ensure the continuity of the Tamarind population on farmland, is necessary in this study area.

*Dobera glabra* was found in association with *T. indica* on farmlands in the study area. We observed that farmers deliberately retain vital edible fruit trees on their farmlands. Such trees could play a vital role in food security, because their fruit are generally collected for subsistence use by local communities [16,37–39]. Furthermore, trees on farms perform important ecological functions, including the provision of soil nutrients [40]. Thus, fruit trees found on farmland in the study area might provide both ecological and social services; however, further empirical studies are needed to verify this assumption. In this regard, the social services included the production of food, fuel, fiber, and other harvestable goods [41]. Also, the cultural services such as recreational, aesthetic, spiritual, and other nonmaterial benefits could be included as the social benefits of farmland trees [42]. Similarly, the ecological services could include the fundamental processes necessary for the production of other services, including soil formation, nutrient cycling and photosynthesis [42].

Although many tropical fruit trees do not have a large world market, their products still have considerable importance in local and national economies and are harvested by rural populations for local consumption and commercialization on a small scale [43].

In this study, the productivity (i.e., the number of fruit per tree and fruit yield/mass) of *T. indica* significantly varied between the two land-use types, with higher levels of productivity recorded for trees growing on farmland than in bushland. Although fruit yield varies seasonally, the number of fresh fruit and the yield per Tamarind tree on farmland was 42% and 64% higher, respectively, than that in bushland. Although the seasonal variation of the yield is usually related with the environmental conditions, the effect may vary with plant species [17]. These results are consistent with the findings of other studies that wild edible trees on farms produce more fruit than unmanaged trees in woodlands [44,45]. Such significant differences in fruit yield under different land-use types might be attributable to differences in environmental variables, such as soil type, landforms, and moisture content [46]. For example, the study on fruit production of *T. indica* across three different ecological regions in Benin indicated that Tamarind trees tend to invest in a small number of very large fruits under wetter conditions and a very large number of small fruits under dryer conditions, indicating the effect of ecological conditions such as temperature and rainfall on the productivity of Tamarind fruits [17]. The level of tree management on farmland has also been reported to significantly influence the degree of competition among trees for available resources such as nutrients [45] and, thus, the productivity of trees in terms of fruit weight and size [44]. Thus, in this study the higher fruit yields from farmland compared with bushland implies that Tamarind trees could benefit from improved management on farms such as hoeing, weeding and reduced competition with other trees [47]. However, although Tamarind trees may tend to produce a large number of high weight fruit under farmland conditions, the majority of the sampled trees produced between 2000 and 5000 fruit per trees. This may indicate that *T. indica* trees growing on farmland have undergone intentional selection owing to local communities removing less-productive trees from farms, suggesting that fruit yields could be further improved through deliberate selection of superior yielding trees from farmland types in the study area. Thus, further surveys of trees on farmland should be carried out to identify superior germplasm that could be used to play a vital role in enhancing fruit production as part of the domestication process of this species.

The relationship between fruit yield per tree and tree dendrometric parameters was expressed by multinomial classification model. The model with grouped dendrometric parameter predictor such as tree size, crown structure and tree branches yielded reliable equations with the lowest AIC values. In order to increase the practical usefulness of the model and to avoid large errors in the estimation of Tamarind fruit yield, models with one dendrometric parameter predictor from each group were chosen. The identified model allowed an accurate fruit yield estimation obtained from the farmland- and bushland-use types of the study area. In this regard, the models holding the combination of DBH, crown diameter, crown volume, crown surface area and number of branches were used to predict Tamarind fruit production from the farmland-use type, while the parameters of the DBH, crown diameter and number of branches were used to develop models for bushland-use type. Similar types of studies have also concluded that the chosen tree parameters best predicted the fruit yield of *Vitex* trees under different land-use conditions [47], whereas other studies have suggested that DBH measurements better estimate fruit yields of *Baobab* [48] and *Vitex* trees [27] using a linear regression models. However, the tree size, crown structure and number of branches of Tamarind trees are affected by environmental and geographical factors such as rainfall, temperature, latitude and longitude, and soil conditions [49,50], which directly affect the accuracy of the models when used for fruit estimation in other places than the study area. Thus, the use of site-specific model may be recommendable for more accurate fruit yield estimations of Tamarind trees. On the other hand, the tree slenderness often serves as an index of tree stability, or the resistance to wind throw [51], although the likelihood of wind throw of a tree may be also influenced by different interacting factors. In this study, the result indicated that the tree slenderness value of the bushland-use type is higher than that of the farmland, indicating that the higher slenderness occurs for the trees with higher height length and smaller diameter distributions. The smaller slenderness is usually indicating a higher resistance to wind throws. Thus, tree treatments, such as producing long-crowned trees, and maintaining appropriate stand density through spacing, thinning, or gradually harvesting over story trees, can be helpful in reducing the risk of wind throw of the farmland-use Tamarind trees in the study area. In this study, the correlation of dendrometric parameters suggested that under enhanced management, Tamarind trees in both land-use types could achieve better yields and structure. However, since *T. indica* can be grown in a diverse dryland area of Ethiopia, a comprehensive study considering management and germplasm selection is required to validate the equation developed in this study.

## 5. Conclusions

This study highlighted the population status of *T. indica* trees under two types of land-use in Dello Menna, Southeastern Ethiopia. We have also provided useful preliminary information on the variation in fruit yield in Tamarind of the two land-use types. Overall, there were a higher number of seedlings and large sized Tamarind trees per hectare on farmland than in bushland, indicating that matured trees are well preserved on farmlands. However, we could not find tree size classes between seedling and mature trees on farmland, whereas well-structured tree size classes were observed in bushland. This situation is likely to have long-term consequences for the population continuity of Tamarind trees on farmland in the long run. Thus, management plans to develop meaningful stand structures on farmland need to be established to ensure the continuity of the Tamarind population in the studied area, either by planting new Tamarind seedlings in specific plots sites or by conserving some of the existing seedlings during the preparation of the soils for new cultivation. Although higher Tamarind fruit yields were obtained from trees growing on farmland than in bushland in the Dello Menna district, the majority of farmland trees produced <5000 fruit per tree.

Classificatory models revealed that, among the tree size variables, DBH was more suitable to predict the fruits yield category than the height of the trees. Similar results were observed for crown related variables such as crown depth, crown volume and crown surface in the farmlands, whereas crown diameter provide the best results in the bushlands. Finally, the number of branches was always significantly related, as we expected, with the yield classification. Thus, the obtained models indicated that the fruit yields of Tamarind trees could be improved through management under different tree size, crown structure and tree branch category. Furthermore, the yield improvement can be done through deliberate selection of higher fruit yielder trees, taking into consideration that Tamarind could grow in more diverse dryland areas in Ethiopia. These strategies might also lead to the development of a sustainable fruit supply in rural areas for commercialization or subsistence use. The findings from this study provide baseline information that could be used to promote the conservation and sustainable uses of valuable wild edible tree species such as Tamarind under different land-use types in Ethiopia. The application of this baseline information is immense and could also assist other developing countries with valuable wild edible trees that are facing similar issues due to land-use change. However, as the present study was based on single-year data, several years of monitoring are needed to precisely model the yield production, taking into consideration the environmental variables such as soil, rainfall, temperature, together with tree genetic variation and inter-annual variation in fruit yield in order to understand the Tamarind productivity better in the study area.

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## References

1. Friis, B.; Demissew, S.; Breugel, P. *Atlas of the Potential Vegetation of Ethiopia*; The Royal Danish Academy of Sciences and Letters: Copenhagen, Denmark, 2010.
2. Teketaye, D.; Limenih, M. *Role of Forestry in Poverty Alleviation in Ethiopia*; Wondo Genet College of Forestry: Shashemenie, Ethiopia, 2005.
3. Eshete, A.; Teketay, D.; Hulten, H. The socio-economic importance and status of populations of Boswellia papyrifera (Del.) Hochst. in northern Ethiopia: The case of North Gonder Zone. *For. Trees Livelihoods* **2005**, *15*, 55–74. [CrossRef]
4. Dejene, T.; Lemenih, M.; Bongers, F. Manage or convert Boswellia woodlands? Can frankincense production payoff? *J. Arid Environ.* **2013**, *89*, 77–83. [CrossRef]
5. Mengistu, T.; Teketay, D.; Hulten, H.; Yemshaw, Y. The role of enclosures in the recovery of woody vegetation in degraded dryland hillsides of central and northern Ethiopia. *J. Arid Environ.* **2005**, *60*, 259–281. [CrossRef]
6. Dejene, T.; Agamy, M.S.; Agúndez, D.; Martín-Pinto, P. Ethnobotanical Survey of Wild Edible Fruit Tree Species in Lowland Areas of Ethiopia. *Forests* **2020**, *11*, 177. [CrossRef]
7. Chikamai, B.; Tchatat, M.; Tieguhong, J.; Ndoye, O. Forest Management for Non-Wood Forest Products and Services in Sub-Saharan Africa. *Discov. Innov.* **2009**, *21*. [CrossRef]
8. Azene, B.; Birnie, A.; Tengnas, B. *Useful Trees and Shrubs for Ethiopia. Identification, Propagation and Management for Agricultural and Pastoral Communities*; Regional Soil Conservation Unit (RSCU), Swedish International Development Authority: Nairobi, Kenya, 1993.
9. Kumar, C.S.; Bhattacharya, S. Tamarind Seed: Properties, Processing and Utilization. *Crit. Rev. Food Sci. Nutr.* **2008**, *48*, 1–20. [CrossRef] [PubMed]
10. Irvine, F.R. *Woody Plants of Ghana with Special Reference to Their Uses*; Oxford University Press: London, UK, 1961.
11. Hocking, D. *Trees for Drylands*; Oxford & IBH Publishing Co Pvt. Ltd.: New Delhi, India, 1993.
12. Sahni, K. *Important Trees of the Northern Sudan. United Nations and FAO*; United Nations and FAO: Rome, Italy, 1968.
13. Gunasena, H.P.; Hughes, A. *Tamarind: Tamarindus indica L.*; International Centre for Underutilised Crops, University of Southampton: Southampton, UK, 2000.
14. Girmay, H.; Tewolde-Berhan, S.; Hishe, H.; Asfaw, Z.; Ruelle, M.; Power, A. Use and management of tamarind (Tamarindus indica L., Fabaceae) local morphotypes by communities in Tigray, Northern Ethiopia. *For. Trees Livelihoods* **2020**, *29*, 81–98. [CrossRef]
15. Mengistu, F.; Hager, H. Wild edible fruit species cultural domain, informant species competence and preference in three districts of Amhara region, Ethiopia. *Ethnobot. Res. Appl.* **2008**, *6*, 487–502. [CrossRef]
16. Lulekal, E.; Asfaw, Z.; Kelbessa, E.; Van Damme, P. Wild edible plants in Ethiopia: A review on their potential to combat food insecurity. *Afr. Focus* **2011**, *24*. [CrossRef]
17. Fandohan, B.; Assogbadjo, A.E.; Kakaï, R.G.; Sinsin, B. Geographical distribution, tree density and fruit production of Tamarindus indica L. (Fabaceae) across three ecological regions in Benin. *Fruits* **2011**, *66*, 65–78. [CrossRef]
18. Sundriyal, M.; Sundriyal, R. Wild edible plants of the Sikkim Himalaya: Nutritive values of selected species. *Econ. Bot.* **2001**, *55*, 377–390. [CrossRef]
19. Paul, A.; Khan, M.L.; Das, A.K. Population structure and regeneration status of rhododendrons in temperate mixed broad-leaved forests of western Arunachal Pradesh, India. *Geol. Ecol. Landsc.* **2019**, *3*, 168–186. [CrossRef]
20. Duchok, R.; Kent, K.; Khumbongmayum, A.; Ashish, P.; Paul, A. Population structure and regeneration status of medicinal tree Illicium griffithii in relation to disturbance gradient in temperate broad-leaved forest of Arunachal Pradesh. *Curr. Sci.* **2005**, *89*, 673–676.
21. Ermias, L.; Ensermu, K.; Tamrat, B.; Haile, Y. Plant species composition and structure of the Mana Angetu mosit montane forest, south-eastern Ethiopia. *J. East. Afr. Nat. Hist.* **2008**, *97*, 165–185.
22. Senbeta, F. Biodiversity and ecology of Afromontane rainforests with wild *Coffea arabica* L. populations in Ethiopia. *Ecol. Dev. Ser.* **2006**, *36*, 1–9.
23. Kevin, M. Quantitative Analysis by the Point-Centered Quarter Method. *arXiv* **2015**, arXiv:1010.3303v2.
24. Sundriyal, M.; Sundriyal, R.C. Structure, phenology, fruit yield, regeneration and marketing status of some prominent ethnobiological plant species of the Sikkim Himalaya, India. *J. Ethnobiol.* **2004**, *24*, 113–138.

25. Cunningham, A. *Applied Ethnobotany: People, Wild Plant Use and Conservation*, 1st ed.; Routledge: Oxfordshire, UK, 2001.
26. Agwu, O.P.; Bakayoko, A.; Jimoh, S.O.; Jatto, S.O.S.; Porembski, S. Influences of Land use type and Dendrometric Variables on fruit production of Garcinia kola Heckel in Nigeria. *Trees For. People* **2020**, *2*, 100015. [CrossRef]
27. Miller, K.; Dietz, J.M. Fruit yield, not DBH or fruit crown volume, correlates with time spent feeding on fruits by wild Leontopithecus rosalia. *Int. J. Primatol.* **2004**, *25*, 27–39. [CrossRef]
28. Umaña-Hermosilla, B.; de la Fuente-Mella, H.; Elórtegui-Gómez, C.; Fonseca-Fuentes, M. Multinomial Logistic Regression to Estimate and Predict the Perceptions of Individuals and Companies in the Face of the COVID-19 Pandemic in the Ñuble Region, Chile. *Sustainability* **2020**, *12*, 9553. [CrossRef]
29. Coughenour, C.; Paz, A.; de la Fuente-Mella, H.; Singh, A. Multinomial logistic regression to estimate and predict perceptions of bicycle and transportation infrastructure in a sprawling metropolitan area. *J. Public Health* **2015**. [CrossRef] [PubMed]
30. Yanagihara, H.; Kamo, K.; Imori, S.; Satoh, K. Bias-corrected AIC for selecting variables in multinomial logistic regression models. *Linear Algebra Appl.* **2012**, *436*, 4329–4341. [CrossRef]
31. Beasom, S.L.; Haucke, H.H. A Comparison of Four Distance Sampling Techniques in South Texas Live Oak Mottes. *J. Range Manag.* **1975**, *28*, 142. [CrossRef]
32. Saha, D.; Sundriyal, R. Prioritization of non-timber forest produces for income generation: A participatory approach. *J. Non-Timber For. Prod.* **2010**, *17*, 387–394.
33. Getachew, T.; Tamrat, B.; Sebsebe, D. Dryland woody vegetation along an altitudinal gradient on the eastern escarpment of Welo, Ethiopia. *Ethiop. J. Sci.* **2008**, *31*, 43–54.
34. Didita, M.; Nemomissa, S.; Gole, T.W. Floristic and structural analysis of the woodland vegetation around Dello Menna, southeast Ethiopia. *J. For. Res.* **2010**, *21*, 395–408. [CrossRef]
35. Djossa, B.A.; Fahr, J.; Wiegand, T.; Ayihouénou, B.E.; Kalko, E.K.; Sinsin, B.A. Land use impact on Vitellaria paradoxa C.F. Gaerten. stand structure and distribution patterns: A comparison of Biosphere Reserve of Pendjari in Atacora district in Benin. *Agrofor. Syst.* **2008**, *72*, 205–220. [CrossRef]
36. Chivaura-Mususa, C.; Campbell, B.; Kenyon, W. Special Section: Land Use Options in Dry Tropical Woodland Ecosystems in Zimbabwe. *Ecol. Econ.* **2000**, *33*, 395–400. [CrossRef]
37. Agúndez, D.; Douma, S.; Madrigal, J.; Gómez-Ramos, A.; Vinceti, B.; Alía, R.; Mahamane, A. Conservation of food tree species in Niger: Towards a participatory approach in rural communities. *For. Syst.* **2016**, *25*. [CrossRef]
38. Faye, M.D.; Weber, J.C.; Abasse, T.A.; Boureima, M.; Larwanou, M.; Bationo, A.B.; Diallo, B.O.; Sigué, H.; Dakouo, J.M.; Samaké, O.; et al. Farmers' preferences for tree functions and species in the west African sahel. *For. Trees Livelihoods* **2011**, *20*, 113–136. [CrossRef]
39. Jaenicke, H.; Hoschle-Zeledon, I. *Strategic Framework for Underutilized Plant Species Research and Development*; ICUC, Colombo and Global Facilitation Unit for Underutilized Species: Rome, Italy, 2006.
40. Manning, A.D.; Fischer, J.; Lindenmayer, D.B. Scattered trees are keystone structures—Implications for conservation. *Biol. Conserv.* **2006**, *132*, 311–321. [CrossRef]
41. Gruenewald, H.; Brandt, B.K.V.; Schneider, B.U.; Bens, O.; Kendzia, G.; Hüttl, R.F. Agroforestry systems for the production of woody biomass for energy transformation purposes. *Ecol. Eng.* **2007**, *29*, 319–328. [CrossRef]
42. Garbach, K.; Lubell, M.; DeClerck, F.A.J. Payment for Ecosystem Services: The roles of positive incentives and information sharing in stimulating adoption of silvopastoral conservation practices. *Agric. Ecosyst. Environ.* **2012**, *156*, 27–36. [CrossRef]
43. Diallo, B.O.; Mckey, D.; Chevallier, M.H.; Joly, H.I.; Hossaert-Mckey, M. Breeding system and pollination biology of the semi-domesticated fruit tree, *Tamarindus indica* L. (Leguminosae: Caesalpinioideae): Implications for fruit production, selective breeding, and conservation of genetic resources. *Afr. J. Biotechnol.* **2008**, *7*, 4068–4075. [CrossRef]
44. Okia, C.A.; Agea, J.G.; Kimondo, J.M.; Abohassan, R.A.A.; Okiror, P.; Obua, J.; Teklehaima, Z. Use and Management of Balanites aegyptiaca in Drylands of Uganda. *Res. J. Biol. Sci.* **2011**, *6*, 15–24. [CrossRef]
45. Shackleton, C.M.; Shackleton, S.E. Household wealth status and natural resource use in the Kat River valley, South Africa. *Ecol. Econ.* **2006**, *57*, 306–317. [CrossRef]
46. Anegbeh, P.O.; Usoro, C.; Ukafor, V.; Tchoundjeu, Z.; Leakey, R.R.B.; Schreckenberg, K. Domestication of Irvingia gabonensis: 3. Phenotypic variation of fruits and kernels in a Nigerian village. *Agrofor. Syst.* **2003**, *58*, 213–218. [CrossRef]
47. Kimondo, J.M.; Okia, C.A.; Agea, J.G.; Abohassan, R.A.A.; Mulatya, J.; Teklehaimanot, Z. Estimating fruit yield from Vitex payos (Lour) merr. in semi-arid eastern province of Kenya: Application of allometric equations. *Res. J. Appl. Sci.* **2011**, *6*, 153–162. [CrossRef]
48. Gebauer, J.; Adam, Y.O.; Sanchez, A.C.; Darr, D.; Eltahir, M.E.S.; Fadl, K.E.M.; Fernsebner, G.; Frei, M.; Habte, T.-Y.; Hammer, K.; et al. Africa's wooden elephant: The baobab tree (*Adansonia digitata* L.) in Sudan and Kenya: A review. *Genet. Resour. Crop. Evol.* **2016**, *63*, 377–399. [CrossRef]
49. Osorio, V.Á.; Muriel, S.B.; Torres, J.M.C. Morphoagronomic characterization of Tamarindus indica L. in orchards of tropical dry forest from Antioquia (Colombia). *Biodivers. Int. J.* **2018**, *2*, 396–403. [CrossRef]
50. Ranaivoson, T.; Brinkmann, K.; Rakouth, B.; Buerkert, A. Distribution, biomass and local importance of tamarind trees in south-western Madagascar. *Glob. Ecol. Conserv.* **2015**, *4*, 14–25. [CrossRef]
51. Wang, Y.; Titus, S.J.; LeMay, V.M. Relationships between tree slenderness coefficients and tree or stand characteristics for major species in boreal mixedwood forests. *Can. J. For. Res.* **1998**, *28*, 1171–1183. [CrossRef]

## Original article - III

# Producción de goma arábiga y estado de la población de *Senegalia senegal* (L.) Britton en bosques de tierras secas en la zona sur de Omo, Etiopía

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## Resumen

*Senegalia senegal* (L.) Britton es una especie de árbol, propia de tierras secas, que produce goma arábiga, un producto de valor comercial. Sin embargo, este recurso está infrautilizado (poco aprovechado) en las zonas secas de Etiopía. El objetivo de este estudio fue evaluar el estado de la población y la producción potencial de goma de *S. senegal* que crece en rodales naturales en la Zona Sur de Omo, Etiopía. Se establecieron 45 parcelas de muestreo, cada una de 20 × 20 m, a intervalos de 500 m a lo largo de los transectos, con subparcelas de 1 $m^2$ ubicadas dentro de las parcelas principales para determinar la regeneración. Los árboles de *S. senegal* con un diámetro a la altura del pecho de entre 2 y 12 cm fueron los más prevalentes. Cuarenta y dos especies de árboles se asociaron con *S. senegal*, de las cuales 16 eran especies productoras de goma y resina. S. senegal se asoció positivamente con *Vachellia tortilis*, *Senegalia mellifera*, *Vachellia nilotica*, *Commiphora edulis* y *Dobera glabra*. *Senegalia senegal* comprendía aproximadamente el 35% de los árboles en regeneración. La producción máxima de goma arábiga obtenida fue de 3948 g $árbol^{-1}$. Los modelos lineales de variables dendrométricas indicaron que la producción de goma arábiga se predice mejor por el diámetro del árbol que por la altura. A pesar de las limitaciones de esta encuesta pionera, el estado de la población y el potencial de producción sugieren que la goma arábiga podría producirse y comercializarse de manera sostenible en rodales naturales de *S. senegal* en las áreas de tierras secas estudiadas, proporcionando a las comunidades locales ingresos estacionales suplementarios.

**Palabras claves:** *Comercialización; goma y resina; Gum arábiga; Senegalia senegal; bosque; resinar*

*sustainability*

MDPI

*Article*

# Gum Arabic Production and Population Status of *Senegalia senegal* (L.) Britton in Dryland Forests in South Omo Zone, Ethiopia

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**Abstract:** *Senegalia senegal* (L.) Britton is a multi-purpose dryland tree species that produces gum arabic, a commercially valuable product. However, this resource is underused in Ethiopian dryland areas. The aim of this study was to evaluate the population status and potential gum yield of *S. senegal* growing in natural stands in South Omo Zone, Ethiopia. Forty-five sample plots, each measuring 20 × 20 m, were established at 500 m intervals along transects, with 1 $m^2$ subplots located within the main plots to determine regeneration. *S. senegal* trees with a diameter at breast height of between 2 and 12 cm were most prevalent. Forty-two tree species were associated with *S. senegal*, of which 16 were gum- and resin-producing species. *S. senegal* was positively associated with *Vachellia tortilis*, *Senegalia mellifera*, *Vachellia nilotica*, *Commiphora edulis*, and *Dobera glabra*. *Senegalia senegal* comprised approximately 35% of regenerating trees. The maximum gum arabic yield obtained was 3948 g $tree^{-1}$. Linear models of dendrometric variables indicated that gum arabic yield is better predicted by tree diameter than by height. Despite the limitations of this pioneer survey, the population status and yield potential suggest that gum arabic could be sustainably produced and commercialized in natural stands of *S. senegal* in the studied dryland areas, providing local communities with supplementary seasonal incomes.

**Keywords:** commercialization; gum and resin; gum arabic; *Senegalia senegal*; stand; tapping



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## 1. Introduction

Forests in dryland areas are a crucial part of the livelihoods of the people that live in these areas worldwide [1,2], while supporting other economic activities through their ecological services and functions [3,4]. If managed properly, dryland forests have the capacity to provide a perpetual stream of non-timber forest products (NTFPs), such as gum and resin, edible plants, wild fruit, medicinal plants, fuelwood, and mushrooms, providing households with food and medicine [5,6]. In addition, sales from NTFPs can provide households with supplementary seasonal incomes [7], especially in times of dwindling economic activities, such as low crop productivity and drought [5,8].

Only 15.7% of Ethiopia is covered by forest [9]. Despite this, the county is rich in bio-diverse forest resources. Nine broad vegetation types are recognized based on climate, vegetation formation (physiognomic and habitat groupings), and associations (species composition/structure) [10]. Among these, dry forests cover some 55 million ha in Ethiopia, and are the largest vegetation resource in the country [10]. These forests are rich in *Acacia*, *Boswellia*, and *Commiphora* species [11,12], which provide important export commodities such as gum arabic, frankincense, and myrrh [11,12]. These products provide an important source of cash income for rural people and are the most important export commodities produced by the forestry sector in Ethiopia [13]. However, dryland forests are continuously shrinking due to the expansion of agricultural lands and human settlements and are suffering from severe degradation due to anthropogenic pressures [10]. Furthermore, despite their important socio-economic and ecological benefits, dry forests are poorly managed and receive no proper silvicultural treatment or attention and, hence, are highly fragmented, have little natural regeneration, and are degraded in terms of species composition and productivity [10]. Thus, the challenges and threat of biodiversity loss persist. Furthermore, the unmonitored exploitation of these dryland regions could have a long-lasting and potentially irreparable effect on the forest ecosystem, as well as on the livelihoods of rural communities [14].

*Senegalia senegal* (L.) Britton is a multipurpose tree species that is grown in dryland areas of Ethiopia, providing socioeconomic and ecological benefits [15]. Natural stands of this species are dominantly found in *Acacia*–*Commiphora* woodlands in the western and southern lowlands of Ethiopia [12,15]. The species is highly valued for its production of gum arabic from trunks, branches and twigs [16]. Gum arabic has a wide range of technological applications in the food, pharmaceutical, and cosmetic industries [16,17] and, hence, is considered a very important economic resource worldwide [18]. *Senegalia senegal* is also ecologically important because it improves soil fertility and is widely used to control desertification [19]. This species is therefore potentially suitable for future reforestation or restoration efforts in moisture-deficient arid and semi-arid areas [19,20]. Furthermore, *S. senegal* trees also provide wood for use as fuel and local construction materials, as well as leaves and pods, which are used as livestock fodder. In addition, the nitrogen-fixing ability of *S. senegal* trees makes them highly suitable for use in agroforestry systems, where they are grown in combination with agricultural crops [17].

Like forest resources in other parts of Ethiopia, dryland forests in the South Nation, Nationalities and People Region (SNNPR) are subject to increasing pressure [4,10]. Deforestation in this area is driven by rapid population growth and the consequent clearance of forests for cropland expansion and by overgrazing [21], which seriously affects the population and regeneration of valuable tree species such as *S. senegal* [22]. Although some studies have investigated the growth performance, gum yield [17], and socioeconomics [4,11] of this species, *S. senegal* populations in different parts of Ethiopia are still inadequately characterized. Managing dry forests so that they can produce a range of NTFPs, such as gum and resin, even to a certain extent in combination with forest-compatible uses such as livestock grazing [11], is considered critical for their continued viability as a source of crucial resources in dryland areas of Ethiopia. Based on these considerations, the National Forests Sector Development Program of Ethiopia (NFSDPE) has devised a strategy to conserve and develop the country's forest resources, with the aim of increasing the proportion of Ethiopia covered by forest from 15% to 20% by 2028 [9]. This strategy also aims to enhance the production and utilization of various NTFPs, such as gum and resin, by undertaking surveying, mapping, and investigations of the resource base and assessing their potential for commercial utilization in dryland areas [9]. Thus, to conserve, manage and use the existing *S. senegal* stands in the South Omo Zone, it is crucial to understand the current population structure, density, and natural regeneration of this species. Furthermore, the conservation and sustained management of *S. senegal* stands appears to depend largely on the benefits that rural households receive from this species. Thus, an estimation of gum arabic yield potential and an understanding of important factors that influence gum production is imperative. Such information could be used to devise management strategies [23] and subsequently provide adequate information for setting appropriate harvest levels based on the status of the species [24,25]. With this goal in mind, the objectives of this study were: (1) to assess the species diversity associated with *S. senegal* trees and the current status and demography of *S. senegal* trees; (2) to evaluate the gum arabic yield potential of *S. senegal* trees; and (3) to evaluate the dendrometric variables associated with *S. senegal* gum production in South Omo Zone, SNNPR, Ethiopia. The information gathered in this research could help to safeguard the longevity and the proliferation of valuable

NTFP-producing tree species in lowland areas, as well as the livelihoods supported by these resources, both in the study area and country-wide.

## 2. Materials and Methods

### *2.1. Description of the Study Area*

The study was conducted in the Bena Tsemay district of the South Omo administrative zone in south-west Ethiopia in the SNNPR (Figure 1). The district is located between 5.11°–5.70° N and 36.20°–37.04° E [26], with average temperatures ranging from 10.1 °C to 27.5 °C and a mean annual rainfall ranging from 400 to 1600 mm. The study area is characterized by bimodal rainfall: the first rainy season occurs from mid-March to the end of April, which is important for crop production; a second short rainy season occurs from mid-October to the beginning of November, which is important for pasture production. The study area is 500–1500 m above sea level (m asl) [26]. The dominant vegetation types are mixed, the *Combretum*–*Terminalia* and *Acacia*–*Commiphora* woodlands, which are used as rangelands and common property resources of the whole community [27].

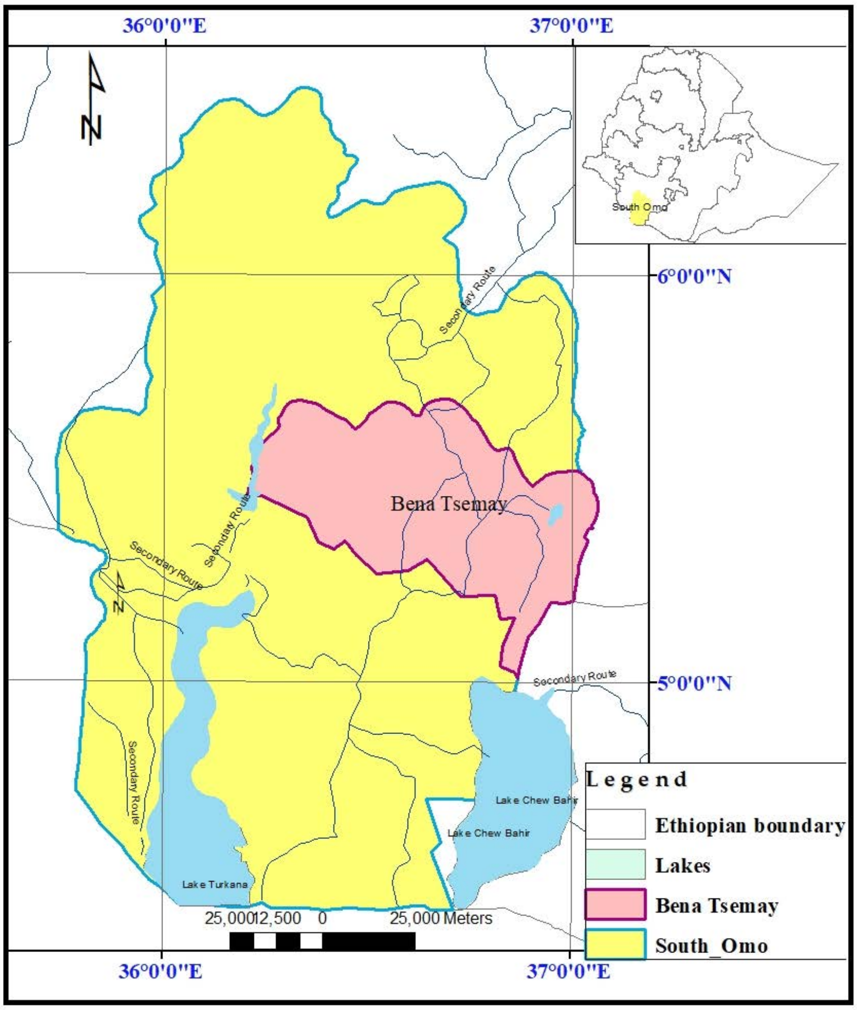


**Figure 1.** Map of the Bena Tsemay district showing the location of the study area, South Omo Zone, Southern Nations Nationalities and People's Region, south-west Ethiopia.

### *2.2. Vegetation Inventory and Data Collection*

Prior to the vegetation survey, a reconnaissance survey was undertaken in order to obtain an impression of the vegetation and topographic features in the study area. Vegetation data were collected in sample quadrants placed along transect lines, which were laid out systematically [28]. A total of 45 plots, 20 × 20 m in area, were laid out along

10 transect lines based on the concept of minimal area [29]. Plots were laid out every 500 m along transect lines, which were laid 400 m apart. All woody plant species, including trees and shrubs, were recorded in the 20 m × 20 m quadrants, whereas seedlings were counted in 1 m × 1 m subplots that were subjectively placed within the main plots [30,31]. All plant species were counted at an individual level within each main plot and subplot. Height and diameter at breast height (DBH) measurements were recorded for any woody plant species with a height ≥ 1.5 m and a DBH ≥ 2 cm. Individual plant with a height < 1.5 m and a DBH < 2 cm were counted [32]. Height and DBH measurements were obtained using a clinometer and a diameter tape, respectively. Plants < 1.5 m in height were measured using calibrated sticks [32]. Every plant species encountered in each plot was recorded using their scientific name. Vernacular names were also recorded whenever possible. For those species that were difficult to identify in the field, plant specimens were collected, pressed and then taken to the Ethiopian Environment and Forestry Research Institute for taxonomic identification. Published volumes of the Flora of Ethiopia and Eritrea [33,34] were used to identify plant specimens.

### *2.3. Gum arabic Yield Estimation*

Gum production from *S. senegal* was evaluated on a per tree basis using the harvesting method [17,35]. Thirty-six individual *S. senegal* gum-producing trees growing in the study area were randomly selected. The selected trees had an almost uniform diameter. They were tagged and tapped with a "sunki" axe to yield strips of relatively similar depth, width, and length. Gum was harvested from each tree in January and February. The gum yield from each harvest was collected in a separate labeled paper bag and weighed using a high-precision balance after drying at room temperature. The total yield data for each tree was obtained by summation.

### *2.4. Data Analysis*

The population structure of *S. senegal* was shown using frequency histograms to depict the diameter classes and the number of seedlings [32]. All individuals of each species encountered in the quadrants were arbitrarily grouped based on their diameter into 5-cm diameter classes (<2 cm, 2–7 cm, 7–12 cm, 12–17 cm, 17–22 cm and >22 cm) [36,37]. Frequency was determined based on the number of plots in which the species was recorded [29]. Density was calculated based on the number of individuals of each species per unit of area [32] using Equation (1).

$$\text{Density/ha} = \left(\sum_{i=1}^{n} \frac{d}{n}\right) \times 25 \tag{1}$$

where d is the number of stems/plot and n is the number of plots. Gum yield (kg) per hectare and year was calculated by multiplying the mean *S. senegal* stem density per hectare calculated above with the mean yield (kg/tree/year) (Equation (2)) following Dejene et al. [31]. Mean gum yield was obtained from previous studies of *S. senegal* [38].

$$\text{Gum yield/ha} = \left(\sum_{i=1}^{n} \left(\frac{d}{n}\right) \times 25\right) \times (\text{y (kg/tree} \times \text{year))} \tag{2}$$

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

The association between the number of *S. senegal* trees and the number of other vascular tree species in the study area was assessed through matrices showing correlation coefficients and their significance levels using libraries "Hmisc" and "corrplot" in R [39]. The relationship between gum yield and individual tree attributes was determined through linear regression. The power of regression equations was seen by their R-values. Coefficients of each equation were used to estimate the gum yield of individual trees. Data were analyzed using R software [39].

## 3. Results

### *3.1. Species Composition and Size Structures*

Forty-two tree species belonging to 26 genera and 13 families were recorded in woodland in the study area (Table 1). The majority of the species (83%) belonged to one of six families: the Fabaceae (14 species), Burseraceae (ten species), Malvaceae (four species), Combretaceae (three species), Anacardiaceae (two species), and Capparaceae (two species). The other seven families were represented by only a single species (Table 1). Sixteen tree species, including seven species of *Commiphora*, five species of *Acacia* (in the genus name of the *Vachellia* and *Senegalia*), and two species of *Combretum*, were identified as sources of either commercial gum and resins or adulterants. The genera *Sterculia* and *Boswellia* were each represented by one species. In terms of tree density, *S. senegal* had the fourth highest density (41 individual stems ha$^{-1}$), thus accounting for 7% of stems. The most prevalent species in the study area were *Boswellia neglecta* (91 individual stems ha$^{-1}$) and the gum- and resin-producing trees *Boscia coriacea* (70 individual stems ha$^{-1}$) and *Commiphora africana* (55 individual stems ha$^{-1}$) (Table 1).

**Table 1.** Density (individual stems ha$^{-1}$ with a DBH $\geq$ 2 cm) of trees and percentage of each tree species recorded in woodland in the study area, South Omo Zone, Ethiopia.

| No. | Species | Family | Density (ha$^{-1}$) | (%) | GR |
|---|---|---|---|---|---|
| 1 | *Acokanthera schimperi* (A.DC.) Oliv. | Fabaceae | 1 | 0.17 | |
| 2 | *Albizia schimperiana* Oliv. | Fabaceae | 40 | 6.29 | |
| 3 | *Annona senegalensis* Pers. | Annonaceae | 3 | 0.42 | |
| 4 | *Balanites aegyptiaca* (L.) Delile | Zygophyllaceae | 14 | 2.27 | |
| 5 | *Berchemia discolor* (Klotzsch) Hemsl. | Rhamnaceae | 2 | 0.25 | |
| 6 | *Boscia coriacea* Pax | Capparaceae | 70 | 10.99 | |
| 7 | *Boswellia neglecta* S.Moore | Burseraceae | 91 | 14.35 | x |
| 8 | *Combretum aculeatum* Vent. | Combretaceae | 4 | 0.67 | x |
| 9 | *Combretum molle* R.Br. ex G.Don | Combretaceae | 2 | 0.25 | x |
| 10 | *Commiphora africana* (A.Rich.) Endl. | Burseraceae | 55 | 8.64 | x |
| 11 | *Commiphora boranensis* Vollesen | Burseraceae | 26 | 4.03 | x |
| 12 | *Commiphora bruceae* Chiov. | Burseraceae | 14 | 2.27 | x |
| 13 | *Commiphora cyclophylla* Chiov. | Burseraceae | 5 | 0.84 | x |
| 14 | *Commiphora edulis* (Klotzsch) Engl. | Burseraceae | 24 | 3.78 | x |
| 15 | *Commiphora erythraea* (Ehrenb.) Engl. | Burseraceae | 3 | 0.50 | |
| 16 | *Commiphora myrrha* (Nees) Engl. | Burseraceae | 15 | 2.35 | x |
| 17 | *Commiphora schimperi* (O.Berg) Engl. | Burseraceae | 31 | 4.95 | |
| 18 | *Commiphora terebinthina* Vollesen | Burseraceae | 16 | 2.52 | x |
| 19 | *Dalbergia melanoxylon* Guill. & Perr. | Fabaceae | 2 | 0.34 | |
| 20 | *Dichrostachys cinerea* (L.) Wight & Arn. | Fabaceae | 3 | 0.42 | |
| 21 | *Dobera glabra* (Forssk.) Juss. ex Poir. | Salvadoraceae | 5 | 0.76 | |
| 22 | *Euphorbia tirucalli* L. | Euphorbiaceae | 4 | 0.59 | |
| 23 | *Faidherbia albida* (Delile) A.Chev. | Fabaceae | 3 | 0.42 | |
| 24 | *Grewia bicolor* Juss. | Malvaceae | 23 | 3.69 | |
| 25 | *Grewia tenax* (Forssk.) Fiori | Malvaceae | 21 | 3.27 | |
| 26 | *Grewia villosa* Willd. | Malvaceae | 36 | 5.71 | |
| 27 | *Lannea schimperi* (Hochst. ex. A. Rich.) Engl. | Anacardiaceae | 24 | 3.78 | |
| 28 | *Maerua angolensis* DC | Capparaceae | 3 | 0.50 | |
| 29 | *Morus mesozygia* Stapf | Moraceae | 3 | 0.42 | |
| 30 | *Piliostigma thonningii* (Schum.) Milne-Redh. | Fabaceae | 3 | 0.42 | |
| 31 | *Sarcocephalus latifolius* (Sm.) E.A.Bruce. | Rubiaceae | 2 | 0.25 | |
| 32 | *Sclerocarya birrea* (A.Rich.) Hochst. | Anacardiaceae | 3 | 0.42 | |
| 33 | *Senegalia brevispica* (Harms) Seigler & Ebinger | Fabaceae | 3 | 0.42 | |
| 34 | *Senegalia mellifera* (M. Vahl) Seigler & Ebinger | Fabaceae | 10 | 1.51 | x |
| 35 | *Senegalia senegal* (L.) Britton | Fabaceae | 41 | 6.54 | x |
| 36 | *Sterculia africana* (Lour.) Fiori | Malvaceae | 7 | 1.17 | x |
| 37 | *Terminalia brownii* Fresen. | Combretaceae | 3 | 0.42 | |
| 38 | *Vachellia oerfota* (Forssk.) Kyal. & Boatwr. | Fabaceae | 2 | 0.25 | |
| 39 | *Vachellia nilotica* (L.) P.J.H.Hurter & Mabb. | Fabaceae | 8 | 1.26 | x |
| 40 | *Vachellia seyal* (Delile) P.J.H.Hurter | Fabaceae | 2 | 0.34 | x |
| 41 | *Vachellia sieberiana* (DC.) Kyal. & Boatwr. | Fabaceae | 2 | 0.34 | |
| 42 | *Vachellia tortilis* (Forssk.) Galasso & Banfi | Fabaceae | 7 | 1.17 | x |

Note: Abbreviation: GR, gum- and resin-producing tree species. The genus names of *Vachellia* and *Senegalia* are also known as *Acacia*.

Most of the *S. senegal* trees were found in the 2–7 cm and 7–12 cm diameter classes than in the larger diameter classes. However, the number of *S. senegal* trees in all diameter classes was significantly lower than that of the total vegetation. The total population status of *S. senegal* and of all the trees recorded is shown in Figure 2A. A comparison of the diameter classes of the three most common gum- and resin-producing tree species indicated that there was a significantly greater number of *B. neglecta* trees in the 2–7 cm diameter class than of *S. senegal* ($p < 0.0001$) or *C. africana* ($p = 0.009$) (Figure 2B), whereas the number of *S. senegal* and *C. africana* trees was not significantly different ($p = 0.661$). Furthermore, in the 7–12 cm diameter class, there were significantly fewer *S. senegal* trees than there were of the other two species ($p < 0.05$). However, in diameter classes with a DBH > 12 cm, the number of trees of each species did not differ significantly ($p > 0.05$) (Figure 2B).

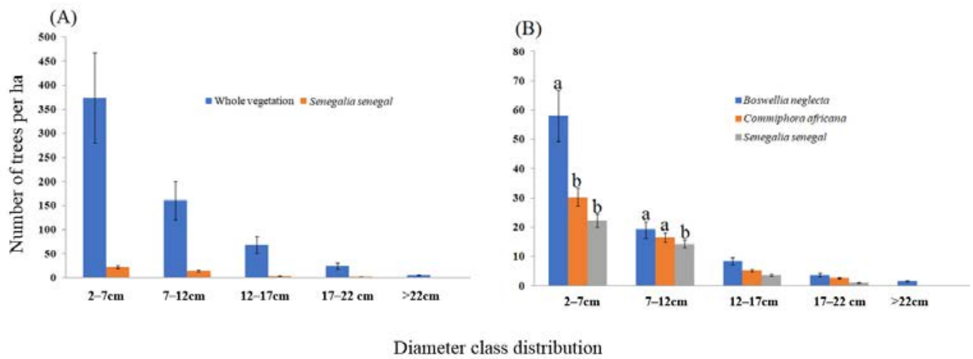


**Figure 2.** Diameter class distribution of the whole vegetation (**A**) and of *Senegalia senegal* trees (**B**) and of the three most prevalent gum- and resin-producing tree species in the study area (South Omo Zone, Ethiopia). Bars represent the standard deviations of the mean. Values with a different letter within a diameter class are significantly different ($p < 0.05$).

In the vegetation composition of the study area, *Senegalia senegal* was positively associated and coexisted mainly with *Vachellia tortilis* (cor = 18%; $p = 0.02$), *Senegalia mellifera* (cor = 17%; $p = 0.025$), *Vachellia nilotica* (cor = 14%; $p = 0.03$), *Commiphora edulis* (cor = 18%; $p = 0.02$), and *Dobera glabra* (cor = 21%; $p = 0.01$) tree species. The associational relationships of the *S. senegal* with other vascular tree species is provided (Figure 3).

### *3.2. Regeneration Status*

We assessed the natural regeneration of the 42 vascular tree species growing in the study area; however, seedlings of only ten species were found (Figure 4), indicating that the regeneration of the other 32 species was hampered by various factors. Among the 10 regenerating tree species, *S. senegal* seedlings were the most abundant (35.15% of seedlings), followed by *Grewia bicolor* (22.65%), and *Commiphora edulis* (18.75%), with the other seven regenerating tree species making up 23.44% of the seedlings (Figure 4).

Among the five gum- and resin-producing tree species showing natural regeneration, *S. senegal* seedlings were the most abundant, followed by *Commiphora edulis*. Together, these two species accounted for approximately 75% of the natural regeneration of gum- and resin-producing tree species, with the other three species making up approximately 25% of the seedlings.

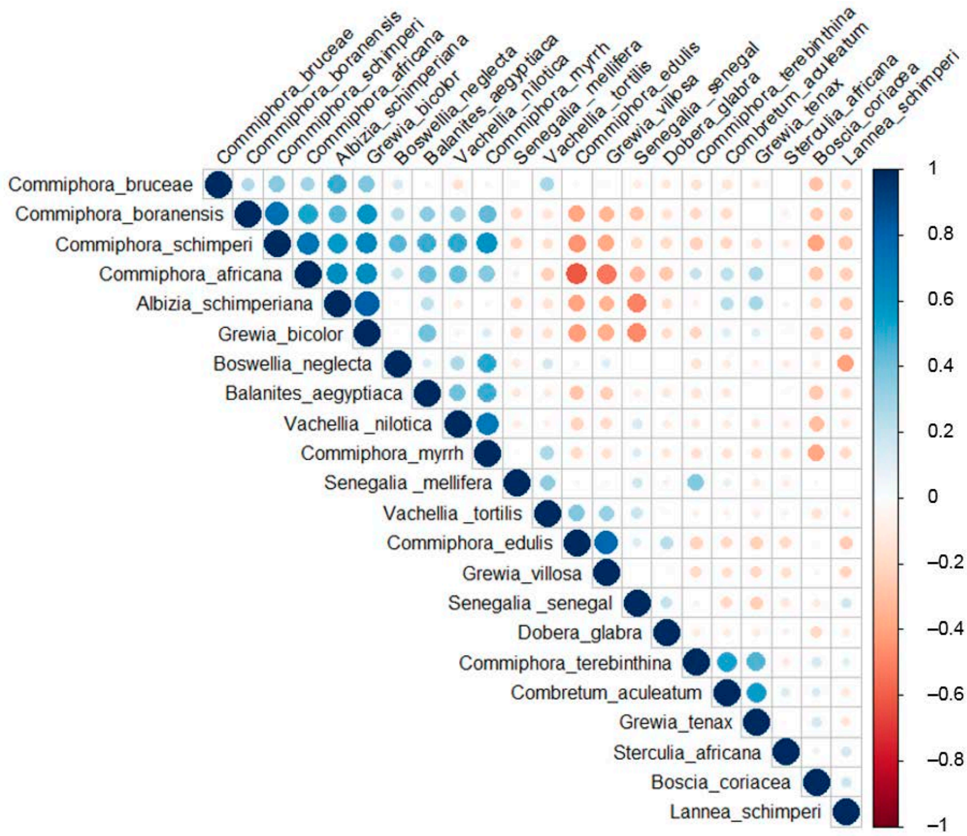


**Figure 3.** Correlation matrix visualizing relationships of the most prevalent vascular plants found in the study area and their relationship with the target tree species (*Senegalia senegal*). Positive correlations are displayed in blue and negative correlations in red. Color intensity and the size of the circle are proportional to the correlation coefficients. On the right-hand side of the correlogram, the legend color shows the correlation coefficients and the corresponding colors. The size of the circle indicates the magnitude of the relationship.

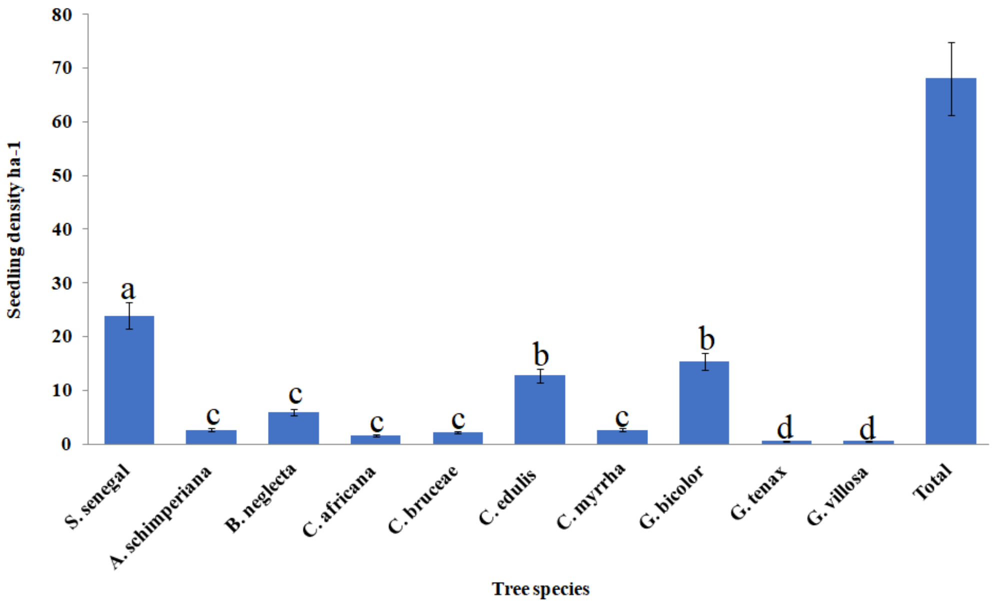


**Figure 4.** Seedling density (individuals $ha^{-1}$) of regenerating tree species in the woodland in the study area, South Omo Zone, Ethiopia. Bars represent the standard deviation of the mean. Values with a different letter are significantly different ($p < 0.05$).

### 3.3. Gum Arabic Yields and Prediction Models

Among the gum-producing *S. senegal* trees, the highest yield obtained from harvests in January and February was 3948 g tree$^{-1}$ whereas the lowest was 266 g tree$^{-1}$. The mean gum yield per tree for the harvests in January and February differed significantly (F = 12.62; $p$ = 0.001), with a higher yield obtained in January (1496 g trees$^{-1}$). The mean stem density of *S. senegal* trees with a diameter $\geq$ 2 cm was 41 stems ha$^{-1}$ (Table 1) and the mean gum yield was 2063 g trees$^{-1}$ year$^{-1}$. Based on these findings, we estimate that a mean gum arabic yield of approximately 190 to 84,578 g ha$^{-1}$ year$^{-1}$ could be expected from two harvests (January and February).

A linear model of the dendrometric variables indicated that gum arabic yield per *S. senegal* tree could be predicted by diameter ($p$ < 0.05) rather than by height. Regressing gum yield against the diameter and height yielded the equations in Figure 5. The R2 value of the diameter indicated that the model fits the data well and that tree diameter could explain 21.48% of the variation in gum arabic yield. The sign of the coefficient for the diameter was positive, which indicates that as tree diameter increases, gum yield also increases. Thus, the average gum yield would increase for every one unit increase in the diameter of *S. senegal* trees.

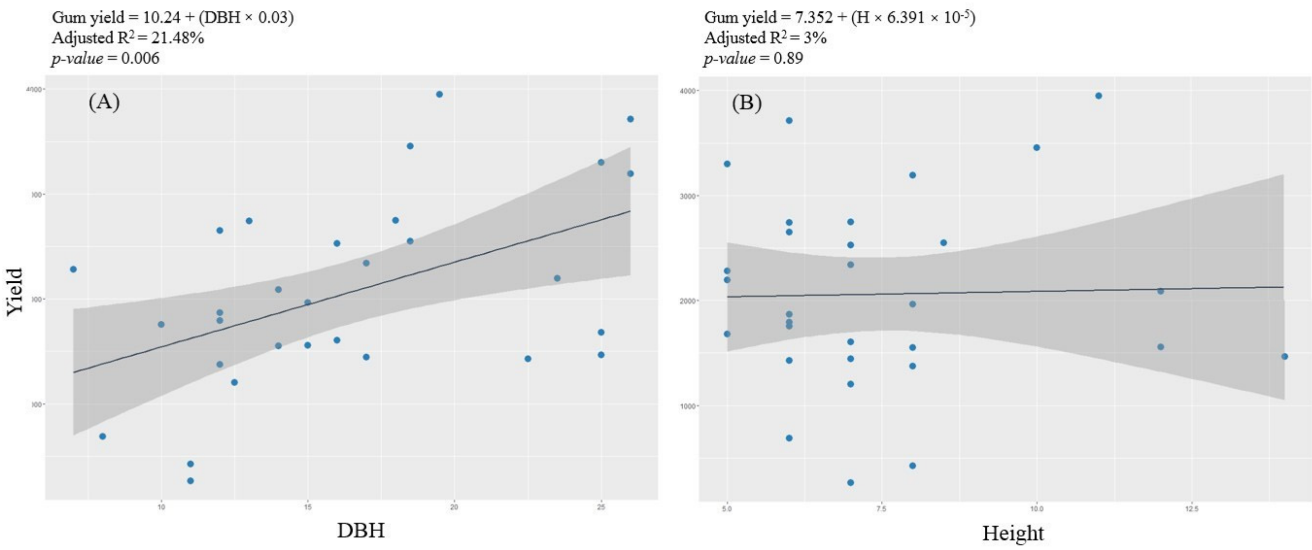


**Figure 5.** Linear regression models of observed and predicted values of gum arabic yield based on (**A**) diameter at breast height (DBH) and (**B**) height of *Senegalia senegal* trees growing in the study area, South Omo Zone, Ethiopia. Blue circles represent the observed gum yield, the black lines indicate the line fit plots and the dark-gray areas indicate the 95% confidence intervals.

## 4. Discussion

Forests in lowland areas in developing countries are important resources with the potential to provide services to rural communities [40]. In Ethiopia, dry forest is the largest remaining type of forest vegetation and more than half (52%) of the country is covered with dryland vegetation, including open canopy forests, wooded savannas, and scrub grasslands [41]. These forests are rich in *Acacia*, *Boswellia*, and *Commiphora* tree species that provide important commodities such as gum arabic, frankincense, and myrrh, respectively [10,42]. In this study, we identified 42 vascular plant species, of which 16 species (38%) were gum- and resin-producing tree species, which were considered the most useful trees. The number of gum- and resin-producing species recorded in this study appears to be higher than that reported to date from other dryland agro-ecologic zones in Ethiopia. For example, only *Senegalia senegal* and *Vachellia seyal* were reported as gum- and resin-producing tree species in a survey of the central Rift valley woodlands of Ethiopia [43]. Other studies of the northern part of Ethiopia have reported *Boswellia papyrifera*, *S. senegal*, *V. seyal*, and *Sterculia setigera* as the main sources of gum and resins [12]. In general, our findings suggest that the South Omo Zone supports more gum- and resin-bearing species than other parts of the country and, hence, there is a greater opportunity for the commercialization of different NTFPs in the form of gum, resin, and myrrh [4,42]. Apart from gum- and resin-bearing tree species, we also found some important wild tree species with edible fruit, such as *Dobera glabra*, which could play a vital role in food security in dryland areas because this fruit is generally collected for subsistence use by local communities [5]. Consistent with other studies, the presence of these valuable tree species among the vegetation of the study area suggests that this forest resource could enhance the livelihoods of local communities through income generated from the various NTFPs [11,32].

Previous studies of gum production have involved stands of *S. senegal* trees with a diameter $\geq$ 4 cm [17]. In this study, we sampled trees with a diameter $\geq$ 2 cm because Yebeyen [43] reported that these trees are considered to be sufficiently mature for gum production purposes. The average density of *S. senegal* trees with a diameter $\geq$ 2 cm was 41 stems ha$^{-1}$ (37% of *S. senegal* stems in the study woodland), which is lower than that reported in other areas of Ethiopia. For example, Yebeyen [43] reported 12–209 *S. senegal* trees ha$^{-1}$ in the rift valley areas of Ethiopia. Similarly, Dejene et al. [31] reported 211 trees ha$^{-1}$ in Abderafi district in north west Ethiopia. The higher density of *S. senegal* in both these areas might be because the vegetation is dominated by *S. senegal* trees in these areas. In our study, *S. senegal* was mainly found in association with *Vachellia tortilis*, *Senegalia mellifera*, *Vachellia nilotica*, *C. edulis*, and *D. glabra*. Most of these species have a wide, dense crown that is umbrella-like and flat-topped [15]. Tree dimensions and structure are of great importance in natural and managed forest ecosystems because they can influence the resource retention capacities of individual trees and, hence, affect their growth and survival [44]. Thus, trees with a dense umbrella-like crown, together with aspects such as the capacity of the forest soil to retain water or rainfall, might limit the number of individual plants per area that can grow under this type of tree and, hence, the overall composition of the vegetation in the ecosystem. Despite the comparatively low density of matured *S. senegal* trees in the study woodland, there is a sufficient number of *S. senegal* trees and associated gum- and resin-producing tree species to support the launch of a commercial gum arabic and resin-harvesting enterprise in the study area. In addition, the regeneration status of *S. senegal* is good compared with that of other species found in the study area, possibly reflecting the abundant seed production of *S. senegal* and their contribution of seeds to the soil seed bank [45]. The thorny nature of *S. senegal* might also help seedlings to escape the browsing effects of cattle [31], which might indicate that *S. senegal* trees are a sustainable resource in this study area.

The average gum arabic yield from tapped trees in this study was 2060 g tree$^{-1}$, with yields ranging from 266 g to 3948 g trees$^{-1}$ in a two-month period, indicating a high level of variation in gum yields among individual trees. Although information on gum yield from different provinces is scarce, our findings agree with those of a similar study conducted in Ethiopia. Alemu et al. [17] showed that gum yield from a managed plantation of *S. senegal* trees could provide on average 96 g per two months of harvesting. Furthermore, a study performed in the Abderafi area, where the woodland is dominated by *S. senegal* trees (211 stems ha$^{-1}$), estimated that 190 to 422 kg ha$^{-1}$ year$^{-1}$ of gum arabic could be harvested, which could be worth approximately $US 950 to 2110 ha$^{-1}$ year$^{-1}$ [31]. The yield estimated in this study is based on two harvests in January and February, which may be a more intensive period of tapping compared with those of other studies, which may have resulted in a lower annual gum yield per hectare in our study area compared with that of other studies. However, taking the overall average gum arabic yield of 2060 g per individual tree and dividing it by 16 tapping seasons, the overall average yield/tree/season would be 129 g per season. Therefore, the predicted yield that could be obtained from the *S. senegal* trees in our study is greater than that predicted by Dejene et al. [31] and Alemu et al. [17] for natural and plantation forests, respectively.

The relationship between gum yield per tree and tree parameters was expressed using linear regression models. The model based on *S. senegal* DBH measurements enabled an accurate estimation of gum yield from the study area woodlands. However, previous studies have indicated that gum yield not only depends on stem diameter but also on the tapping intensity, number of tree branches, direction of tapping and season [16,17]. Furthermore, all these tree parameters are affected by environmental and geographical factors such as rainfall, temperature, latitude and longitude, and soil conditions [46,47], which might have a direct impact on the accuracy of the models. Our model based on DBH measurements provides new insights regarding the potential commercial development of gum arabic production in dryland areas as an off-farm activity to supplement the household economy of local communities together with the other associated gum- and resin-producing tree species. However, further models that include more ecological variables should be developed to extrapolate this potentiality to other understudied areas. Furthermore, the findings from this preliminary study could be used to estimate the gum arabic yield per tree and season in natural stands in the study area. Yield assessments should also be carried out for several seasons to determine the best tapping time/dates.

## 5. Conclusions

This study highlighted the population status of *Senegalia senegal* trees in a dryland area of South Omo Zone, SNNPR, Ethiopia. In addition, we have provided useful preliminary information on gum yield and a model based on *S. senegal* DBH measurements as a predictor for potential gum yield by this species. However, further modeling studies are needed to incorporate environmental and geographical factors that affect tree parameters to determine whether these factors influence the accuracy of the yield model. Further yield assessments should be carried out for several seasons to determine the best tapping time. Overall, there is a good level of regeneration and the diameter distribution of individual *S. senegal* trees indicates that most are mature enough to be tapped. This indicates that gum arabic harvesting could be started in this area if appropriate management activities are applied. Thus, this study provides baseline information that could be used for planning future economic development in the study area based on the use of NTFPs, mainly gum- and resin-production, through considering the multiple uses of gum- and resin-producing species. The findings from this study also provide baseline information about gum yield that could be used to promote the protection, conservation, planting, taping, or commercial use of the *S. senegal* trees in South Omo Zone, Ethiopia. The gum yield data could be used to estimate gum arabic yields per *S. senegal* tree per year in the study area at different density levels and could also be used to assist other developing countries with valuable but underutilized trees like *S. senegal* that produce NTFPs. However, before gum arabic production can begin, management plans need to be established for natural forests to ensure the continuity and sustainability of gum arabic production, either by limiting production levels or the number of stems in different DBH classes that can be tapped.

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## References

1. Paumgarten, F.; Shackleton, C. Wealth differentiation in household use and trade in non-timber forest products in South Africa. *Ecol. Econ.* **2009**, *68*, 2950–2959. [CrossRef]
2. Shackleton, S.; Campbel, L.; Lotz-Sisitka, H.; Shackleton, C. Links between the local trade in natural products, livelihoods and poverty alleviation in a semi-arid region of South Africa. *World Dev.* **2008**, *36*, 505–526. [CrossRef]
3. Chikamai, B.; Tchatat, M.; Tieguhong, J.; Ndoye, O. Forest management for non-wood forest products and services in Sub-Saharan Africa. *Discov. Innov.* **2009**, *21*. [CrossRef]
4. Worku, A.; Lemenih, M.; Fetene, M.; Teketay, D. Socio-economic importance of gum and resin resources in the dry woodlands of Borana, southern Ethiopia. *For. Trees Livelihoods* **2011**, *20*, 137–155. [CrossRef]
5. Melaku, E.; Ewnetu, Z.; Teketay, D. Non-timber forest products and household incomes in Bonga forest area, southwestern Ethiopia. *J. For. Res.* **2014**, *25*, 215–223. [CrossRef]
6. Saifullah, M.K.; Kari, F.B.; Othman, A. Income dependency on non-timber forest products: An empirical evidence of the indigenous people in Peninsular Malaysia. *Soc. Indic. Res.* **2018**, *135*, 215–231. [CrossRef]
7. Dejene, T.; Oria-de-Rueda, J.A.; Martín-Pinto, P. Wild mushrooms in Ethiopia: A review and synthesis for future perspective. *For. Syst.* **2017**, *26*, eR04. [CrossRef]
8. Dovie, D.B.K. Rural economy and livelihoods from the non-timber forest products trade. Compromising sustainability in southern Africa? *Int. J. Sustain. Dev. World Ecol.* **2003**, *10*, 247–262. [CrossRef]
9. MEFCC. *National Forest Sector Development Program, Ethiopia. Volume II: Program. Pillars, Action Areas and Targets*; Ministry of Environment, Forestry, and Climate Change: Addis Ababa, Ethiopia, 2018.
10. Lemenih, M.; Bongers, F. Dry forests of Ethiopia and their silviculture. In *Silviculture in the Tropics, Tropical Forestry 8*; Günter, S., Weber, M., Stimm, B., Mosandl, R., Eds.; Springer: Berlin/Heidelberg, Germany, 2011; pp. 261–272.
11. Dejene, T.; Lemenih, M.; Bongers, F. Manage or convert Boswellia woodlands? Can frankincense production payoff? *J. Arid Environ.* **2013**, *89*, 77–83. [CrossRef]
12. Eshete, A. *The Frankincense Tree of Ethiopia: Ecology, Productivity and Population Dynamics*; Wageningen University: Wageningen, The Netherlands, 2011.
13. Lemenih, M.; Kassa, H. *Opportunities and Challenges for Sustainable Production and Marketing of Gums and Resins in Ethiopia*; CIFOR: Bogor, Indonesia, 2011; ISBN 978-602-8693-57-8.
14. Gidey, T.; Hagos, D.; Juhar, H.M.; Solomon, N.; Negussie, A.; Crous-Duran, J.; Oliveira, T.S.; Abiyu, A.; Palma, J.H. Population status of *Boswellia papyrifera* woodland and prioritizing its conservation interventions using multi-criteria decision model in northern Ethiopia. *Heliyon* **2020**, *6*, e05139. [CrossRef]
15. Azene, B.; Birnie, A.; Tengnas, B. *Useful Trees and Shrubs for Ethiopia. Identification, Propagation and Management for Agricultural and Pastoral Communities*; Regional Soil Conservation Unit (RSCU), Swedish International Development Authority: Nairobi, Kenya, 1993.
16. Wekesa, C.; Makenzi, P.; Chikamai, B.N.; Lelon, J.K.; Luvanda, A.M.; Muga, M. Gum Arabic yield in different varieties of Acacia senegal (L.) Willd in Kenya. *Afr. J. Plant. Sci.* **2009**, *3*, 263–276.
17. Alemu, A.; Yilma, Z.; Eshete, A.; Dejene, T. Growth performance and gum Arabic production of Acacia Senegal in northwest lowlands of Ethiopia. *J. For. Res.* **2013**, *24*, 471–476. [CrossRef]
18. Goodrum, L.J.; Patel, A.; Leykam, J.F.; Kieliszewski, M.J. Gum Arabic glycoprotein contains glycomodules of both extensin and arabinogalactan-glycoproteins. *Phytochemistry* **2000**, *54*, 99–106. [CrossRef]
19. Raddad, E.Y.; Luukkanen, O. Dryland rehabilitation with Acacia Senegal in the central clay plain of the Sudan: Implications for ecological sustainability and management interventions. *Agric. Res.* **2013**, *22*, 31–48.
20. Sahni, K. *Important Trees of the Northern Sudan*; United Nations and FAO: Rome, Italy, 1968.
21. Lemenih, M.; Kassa, H. Re-greening Ethiopia: History, challenges and lessons. *Forests* **2014**, *5*, 1896–1909. [CrossRef]
22. Lulekal, E.; Asfaw, Z.; Kelbessa, E.; Damme, P. Van Wild edible plants in Ethiopia: A review on their potential to combat food insecurity. *Afr. Focus* **2011**, *24*, 71–121. [CrossRef]
23. Sundriyal, M.; Sundriyal, R.C. Structure, phenology, fruit yield, regeneration and marketing status of some prominent ethnobiological plant species of the Sikkim Himalaya, India. *J. Ethnobiol.* **2004**, *24*, 113–138.
24. Duchok, R.; Kent, K.; Khumbongmayum, A.; Ashish, P.; Paul, A. Population structure and regeneration status of medicinal tree *Illicium griffithii* in relation to disturbance gradient in temperate broad-leaved forest of Arunachal Pradesh. *Curr. Sci.* **2005**, *89*, 673–676.
25. Paul, A.; Khan, M.L.; Das, A.K. Population structure and regeneration status of rhododendrons in temperate mixed broad-leaved forests of western Arunachal Pradesh, India. *Geol. Ecol. Landsc.* **2019**, *3*, 168–186. [CrossRef]
26. Assefa, A.; Abebe, T. Wild edible trees and shrubs in the semi-arid lowlands of Southern Ethiopia. *J. Sci. Dev.* **2010**, *1*, 5–19.

27. Soromessa, T.; Teketay, D.; Sebsebe, D. Ecological study of the vegetation in Gamo Gofa zone, southern Ethiopia. *Trop. Ecol.* **2004**, *45*, 209–221.
28. Didita, M.; Nemomissa, S.; Gole, T.W. Floristic and structural analysis of the woodland vegetation around Dello Menna, southeast Ethiopia. *J. For. Res.* **2010**, *21*, 395–408. [CrossRef]
29. Kent, M.; Coker, P. *Vegetation Description and Analysis: A practical Approach*; Belhaven Press: London, UK, 1992.
30. Wale, H.A.; Bekele, T.; Dalle, G. Plant community and ecological analysis of woodland vegetation in Metema Area, Amhara National Regional State, Northwestern Ethiopia. *J. For. Res.* **2012**, *23*, 599–607. [CrossRef]
31. Dejene, T.; Mohamed, O.; Adamu, H. Stand status and yield economics of *Acacia Senegal* (l) wild at Abderafi, North Western Ethiopia. *Asian J. Agric. Biol.* **2014**, *2*, 129–136.
32. Eshete, A.; Teketay, D.; Hulten, H. The socio-economic importance and status of populations of *Boswellia papyrifera* (Del.) Hochst. in northern Ethiopia: The case of North Gonder Zone. *For. Trees Livelihoods* **2005**, *15*, 55–74. [CrossRef]
33. Hedberg, I.; Edwards, S. *Flora of Ethiopia and Eritria*; Addis Ababa and Asmara, Ethiopia: Uppsala, Sweden, 1989.
34. Teketay, D.; Granström, A. Soil seed banks in dry Afromontane forests of Ethiopia. *J. Veg. Sci.* **1995**, *6*, 777–786. [CrossRef]
35. Saha, D.; Sundriyal, R. Prioritization of non-timber forest produces for income generation: A participatory approach. *J. Non-Timber For. Prod.* **2010**, *17*, 387–394.
36. Tilahun, A. Structure and regeneration status of Menagesha Amba Mariam Forest in Central Highlands of Shewa, Ethiopia. *Agric. For. Fish.* **2015**, *4*, 184. [CrossRef]
37. Ogbazghi, W.; Rijkers, T.; Wessel, M.; Bongers, F. Distribution of the frankincense tree *Boswellia papyrifera* in Eritrea: The role of environment and land use. *J. Biogeogr.* **2006**, *33*, 524–535. [CrossRef]
38. Duke, J. *Handbook of Energy Crops*; Purdue University, Center for New Crops & Plants Products: Lafayette, IN, USA, 1983.
39. Team, R.C. *A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2020.
40. Rowland, D.; Blackie, R.R.; Powell, B.; Djoudi, H.; Vergles, E.; Vinceti, B.; Ickowitz, A. Direct contributions of dry forests to nutrition: A review. *Int. For. Rev.* **2015**, *17*, 45–53. [CrossRef]
41. Lawry, S.; McLain, R.; Kassa, H. *Strengthening the Resiliency of Dryland Forest-Based Livelihoods in Ethiopia and South. Sudan: A Review of Literature on the Interaction between Dryland Forests, Livelihoods and Forest Governance*; Center for International Forestry Research (CIFOR): Bogor, Indonesia, 2015.
42. Lemenih, M.; Kassa, H. Socio-economic and environmental significance of dry land resources of Ethiopia and their development challenges. *J. Agric. Dev.* **2010**, *1*, 71–91.
43. Yebeyen, D. Population Status of *Acacia Senegal* (Linne) Willdenow and Its Gum Quality in the Central Rift Valley of Ethiopia. Master's Thesis, Awassa University, Awassa, Ethiopia, 2006.
44. Schneider, R.; Calama, R.; Martin-Ducup, O. Understanding tree-to-tree variations in stone pine (*Pinus pinea* L.) cone production using terrestrial laser scanner. *Remote Sens.* **2020**, *12*, 173. [CrossRef]
45. Senbeta, F.; Teketay, D. Regeneration of indigenous woody species under the canopies of tree plantations in Central Ethiopia. *Trop. Ecol.* **2001**, *42*, 175–185.
46. Osorio, V.Á.; Muriel, S.B.; Torres, J.M.C. Morphoagronomic characterization of *Tamarindus indica* L. in orchards of tropical dry forest from Antioquia (Colombia). *Biodivers. Int. J.* **2018**, *2*, 396–403. [CrossRef]
47. Ranaivoson, T.; Brinkmann, K.; Rakouth, B.; Buerkert, A. Distribution, biomass and local importance of tamarind trees in south-western Madagascar. *Glob. Ecol. Conserv.* **2015**, *4*, 14–25. [CrossRef]