Investigating the Utilization of Indigenous Forestry as A Pathway for Commercial Forestry, Community Upliftment and Land Restoration

By

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Dissertation Summary

Forests play a vital role in sustaining ecological balance and providing essential resources for human well-being. In South Africa, forestry has predominantly relied on non-indigenous tree species, leading to limited natural forests and an increasing dependence on commercial forest plantations. These plantations are mainly made up of commercial exotic monocultures constituting pine, wattle, and eucalyptus species. Some of these exotic species tend to colonize the natural environments of local indigenous species and grasslands where they ultimately alter the soil and water conditions to outcompete local species. In addition, due to their greater growth forms than indigenous tree species, they alter the structure of natural vegetation which negatively impacts nutrient cycles and water availability. As a result, the need to explore alternative approaches in forestry that prioritize indigenous tree species has become evident.

While indigenous commercial forestry is practiced globally, South Africa has untapped potential due to the limited number of indigenous tree plantations in the country. To explore the use of indigenous trees, the main aim of the project was to investigate the use of indigenous trees for commercial forestry, community development, as well as land restoration by assessing and evaluating the growth and survival of indigenous species through the application of propagation methods and the incorporation of plant growth-promoting fungus *Trichoderma asperellum* (Eco-T). This was followed by assessing ecological benefits of indigenous trees such as biodiversity conservation, soil nutrient analysis, and evaluating cost-effective methods and market potential for indigenous tree propagation, as well as the recovery of trees in anthropogenic soils. This aim was firstly achieved by assessing the feasibility and potential of indigenous forestry in South Africa through a literature search and then further reported on indigenous tree species' importance and utilization along with their associated resources.

Subsequently, this research investigated the utilization of indigenous tree species in South Africa, particularly within three peri-urban communities of the eThekwini municipality, KwaZulu-Natal. The first phase of sampling followed snowballing sampling strategy through assistance from local authorities (N=29), and a questionnaire was administered at one of the focus group discussions (N=10). The second phase of sampling used purposive sampling strategy to identify interviewees (N=10). Ethnobotanical data was collected and a total of 21 indigenous tree species were identified and reported across the three communities, emphasizing the utilization patterns and preferences of local species. Amongst the reported species, 12 species were utilized in either all three or two communities. Across all three sites, four indigenous tree species emerged as the most commonly utilized species, notably, *Sclerocarya birrea*, *Prunas africana*, *Trichilia emetica* and *Ficus sur*, accounting for 90% of participants (n=20). Fruits and medicinal products derived from bark and leaves were the most commonly utilized resource products from indigenous trees, constituting 60% of overall usage by participants. These findings highlighted that indigenous tree species with multiple uses were commonly utilized more than those species with one use, which elucidates the commercial value and economic potential of those. Treepreneurs emerged as pivotal components in this study that showcased profound knowledge and commitment to indigenous tree propagation and cultivation, expressing a clear preference for indigenous species over alien invasive plants. Hence, understanding the perspectives and needs of the local community is essential for the successful implementation of indigenous commercial forestry.

The growth of indigenous tree species under field and greenhouse conditions was assessed. A total of five indigenous tree species namely *Trichilia emetica*, *Harpephyllum caffrum*, *Sclerocarya birrea*, *Ficus sur* and *Canthium inerme* were selected for this study based on the preliminary findings of the ethnobotanical survey. Tree seedling growth and survival were the important parameters evaluated in this study to investigate the impact of *Trichoderma asperellum* (Eco-T) on the growth of indigenous tree species. Noteworthy results obtained from the field growth establishment trial include the highest survival rate *H. caffrum* and the fastest growth in *F. sur*, accounting for 100% and 33.13 cm, respectively. However, the application of *Trichoderma* treatment did not have any significant impact on the growth and survival of the indigenous tree species. These findings lay a great foundation for the cultivation, survival, and growth of indigenous tree species under field conditions.

Greenhouse cultivation of indigenous tree species was conducted using anthropogenic soils from degraded lands. Here, the growth forms of indigenous tree species compared to the exotic species *Eucalyptus grandis* were investigated. The application of Eco-T as a treatment was also examined on the survival and growth of the seedlings. Indigenous tree seedlings exhibited a high survival percentage except for *S. birrea* in both Eco-T treated and untreated samples, accounting for 67 and 92%, respectively. Notably, the overall highest change in growth of height was observed in seedlings of *F. sur* with 48.8 cm but not as high as that of the control sample accounting for 106.16 cm. However, the treatment did not have any significant impact on the growth and survival of indigenous tree species. These results highlight the potential expressed by indigenous tree species especially *F. sur* under field and greenhouse conditions, in forestry and land restoration. They further emphasize the need for the development of specific indigenous tree species of commercial and ecological value.

Furthermore, this study investigated the effect of different rooting hormones in the growth of different indigenous tree species from stem cuttings and then assessed the feasibility of propagating indigenous tree species using cuttings. In this study, four treatments namely Seradix, Dip n Grow, Eco-T and control were tested on three cutting types of the five indigenous tree species. All treatments showed no significant impact on the survival and growth of the species. At the end of the growing period, only one out of five species had survived, sprouted and rooted, accounting for 16% of *F. sur*. High mortality was observed at the end of the growing period (12 weeks) and can be accounted by various factors such as oversaturation on growing medium, temperature, and moisture. The findings revealed to yield great propagation success, compatibility of rooting hormones, type of species and cutting type must be taken into consideration. The findings further reveal the slight feasibility of propagating indigenous tree species from stem cutting, but also express great potential for *F. sur*. Hence, more research and development are needed to explore the potential of *F. sur* as well as other important indigenous tree species that can add value in forestry and be utilized for commercial purposes.

Lastly, this study could provide valuable information for forestry managers, researchers, and policy makers to support the conservation and sustainable management of indigenous tree species. Overall, it can serve as a blueprint for similar initiatives and can be applied in various contexts advocating for a more inclusive, ecologically sound, and sustainable approach in the forestry sector.

Preface

The research and experimental work described in this dissertation was carried out in the Institute of Commercial Forestry Research (ICFR) and the School of Agricultural, Earth, and Environmental Science, University of KwaZulu-Natal, Pietermaritzburg, from March 2021 to January 2024, under the supervision of Dr. Richard Burgdorf, Dr. Nokwazi Mbili, Dr Mallika Sardeshpande and Prof. Mark Laing.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to another university. Where use has been made of the work of others, it is duly acknowledged in the text.

Declaration

I, **Kuhlekonke Khulani Mathenjwa**, declare that:

a. The research reported in this dissertation except otherwise indicated is my original work.

b. This dissertation has not been submitted for any degree or examination at any other university.

c. This dissertation does not contain other person's data, pictures or graphs or other information, unless specifically acknowledged as being sourced from other persons.

d. This dissertation does not contain other person's writing unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, their words have been re-written, but the general information attributed to them has been referenced.

e. This dissertation does not contain text, graphics or tables copied and pasted from the Internet unless specifically acknowledged and the source being detailed in the thesis and in the References section.

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Dedication of work

"To myself, my family, and all those who from a far or near have contributed in any way towards making this project a success and towards the completion of this study"

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Dissertation Introduction

Forestry conducted for commercial purposes through the production of timber, non-timber forest products, and biomass for energy can generate significant economic benefits (Wang *et al.*, 2022). Trees also play a crucial role in food security by providing fruits, nuts, and other edible products, as well as supporting agroforestry systems that enhance agricultural productivity (Kunene *et al.*, 2020). Forestry can also contribute to social upliftment through job creation, fostering sustainable livelihoods, and improving living standards in rural communities. Additionally, well-managed forests enhance ecosystem services, such as soil stabilization and water regulation, further supporting agricultural and community resilience (Khan *et al.*, 2021). Furthermore, the integration of commercial forestry with food security initiatives can facilitate holistic development and poverty alleviation.

Forestry

Forestry is the foundation of sustainable land management and resource utilization, encompassing a broad spectrum of actions critical to environmental stability and human wellbeing (Mwavu *et al.*, 2023). It involves the cultivation, conservation, and responsible use of forests, addressing the intricate balance between human needs and ecological preservation (Mwavu *et al.*, 2023). However, forestry is more than just the cultivation and harvesting of trees; it is a broad field that encompasses the science, art, and practice of fostering and preserving forest ecosystems (Chamberlain *et al.*, 2020; Yego *et al.*, 2021). In this case, forests act as a source of goods and services for millions of people globally that provide a wide range of uses and benefits such as timber and non-timber products (food, medicine, fodder) (Chamberlain *et al.*, 2020). They are a source of livelihood for forest-dependent communities as well as over 25% of the world's population that rely on forest resources for their livelihoods (Chamberlain *et al.*, 2020; Thammanu *et al.*, 2021). Furthermore, these forests provide environmental services that support the well-being of humans which includes regulating climate, and carbon sequestration (Fawzy *et al.*, 2020).

In South Africa, forestry is mostly made up of non-indigenous trees and many indigenous trees have lost their natural habitat to the expansion of exotic plantations that have been occurring over decades (Dyer *et al.*, 2016; Kaptein *et al.*, 2023). South Africa has been a pioneer in the development of plantations with exotic tree species accounting for 1% of the total South African land area compared to 0.5% occupied by natural forests (FSA 2016; Ledger, 2017). The expansion of plantation forests is mainly due to the growing demand for exports of exotic wood production, of which currently pulpwood is the largest market for Roundwood from eucalyptus, whereas wattle contributes to wood chips as well as pine contributing to the production of sawlogs (Morris, 2022). However, this expansion of the area planted with exotic species has caused ecological concerns around an impact on water resources and biodiversity (Kaptein *et al*., 2023). These concerns have been evident due to the gradual increase of eucalyptus plantations that are reported to consume more water as compared to other commercial species (White *et al*., 2014; Kaptein *et al*., 2023). Additionally, some exotic species become invasive; they tend to colonize the natural environments of local indigenous species and grasslands where they alter the soil and water conditions to outcompete local species (Shackleton and Shackleton, 2018; Rai and Singh, 2020). Moreover, due to their greater growth forms than indigenous tree species, invasive exotic species in South Africa have altered the structure of the vegetation which negatively impacts nutrient cycles and water availability (O'Connor *et al*., 2020). Shackleton and Shackleton (2018) and Di Sacco *et al.* (2021) suggest that planting indigenous tree species in reforestation lands can aid in conserving natural lands and biodiversity from the invasion of alien species. For example, in the case of India (Singh, 2008) and Canada (Almas and Conway, 2016) a study reported that to promote the regeneration of degraded or invaded lands, planting natural sources or germplasm is an active approach to conserving natural forests and biodiversity.

The role of forestry in biodiversity

Forestry in South Africa is mostly made up of exotic monocultures that tend to drive biodiversity away (Le Hai Dinh *et al*., 2021). Altamirano *et al.* (2020) reported that in comparison to natural forests, most exotic tree plantations support lower levels of biodiversity and have less potential to provide ecosystem services. Furthermore, primarily, the loss of tree covers and decline in biodiversity have been attributed to exotic tree plantations. More specifically, it accounts for 99%, 56%, 41%, and 29% of the loss of tree cover in Europe, North America, Australia/Oceania, and Russia/China/South Asia, respectively (Curtis *et al.* 2018; Altamirano *et al*., 2020). Evidence suggests exotic monocultures especially from pine, wattle, and eucalyptus species are often susceptible to insect infestation (Brockerhoff *et al*., 2013).

However, the conservation of natural germplasm as well as the planting of more indigenous tree species can help support biodiversity, as an active approach to protecting various species and ecosystem services (Brockerhoff *et al*., 2013). These services include provisioning services, regulating services, supporting services, and cultural services including climate change mitigation and carbon sequestration (Brockerhoff *et al*., 2013; Castro-Díez *et al*., 2019). Forests and trees are essential in climate change mitigation by capturing carbon dioxide through photosynthesis and storage of carbon within forest ecosystems (Wheeler et al., 2016). Thus, planted forests of indigenous tree species and the restoration of degraded forests are likely to increase the quantity of carbon stored in trees and soils (Wheeler *et al*., 2016; Fawzy *et al*., 2020). Moreover, an imminent increase in indigenous forest plantations is likely to support more biodiversity conservation and carbon sequestration (Wheeler *et al*., 2016), and the value of conservation of those plantations depends upon the type of tree species planted (Brockerhoff *et al*., 2013).

The role of forestry in food security

There is also potential for commercially important indigenous trees to be grown in community nurseries as a supplement to mainstream income sources, especially in areas where the cultivation of conventional crops is impractical (Shackleton and Shackleton, 2006). Commercial forestry of indigenous tree species can be part of a new strategy for developing medicinal plants as commercial crops to meet demand and support conservation (Jimu, 2011). These species can play an important role in timber and fruit production for local communities. Furthermore, these indigenous varieties may be more resistant to drought, diseases, and fire and provide other forest products for use by that community and at the same time result in ecosystem restoration (Leakey *et al*., 2022).

Cultivation of indigenous trees by communities has been successful e.g., in the case of the *Prunus africana* project in Cameroon (Gyau *et al*., 2012). The wild populations of this forest tree (known as the African cherry) were heavily exploited for medicinal purposes and bark products from Africa were exported to Europe and constituted the largest volume of any African medicinal plant in international trade (Jimu, 2011). Many examples also exist of underutilized indigenous tree species e.g., Kei apple (*Dovyalis caffra*), Wild medlar (*Vangueria infausta*), Marula (*S. birrea*) (Mabhaudhi *et al*., 2016; Sardeshpande *et al*., 2023), and other edible indigenous fruit trees such as Red Ivory (*Berchemia zeyheri*), Wild plum (*Harpephyllum Caffrum*) and Monkey orange (*Strychnos spinosa*) (Shai *et al*., 2020; Van Rayne *et al*., 2023) which can make a significant contribution to local community nutrition and income generation as well as food security (Chamberlain *et al*., 2020; Shai *et al*., 2020). Thus, the cultivation of more resilient indigenous crops and tree species is increasingly important for food security in the face of climate change (Hanjra and Qureshi, 2010; Chamberlain *et al*., 2020). Indigenous crops and trees are often adapted and resilient to local conditions and stresses, as well as human disturbance and resource extraction (Gaoue *et al*. 2016, Lankoande *et al*. 2017). Mabhaudhi *et al*. (2016) suggest that this factor allows these tree and crop species to be cultivated because they require fewer modifications and have less impact on the ecological ecosystem in which they are produced.

The adoption of indigenous trees in small-scale forestry and horticulture, implemented through the transfer of commercial forestry skills and knowledge, can be used as a strategy to combat the challenges being faced due to climate change. This is because exotic commercial forestry uses propagation and enhancement techniques to improve plant survival and growth efficiency (Sourmare *et al*., 2021). Numerous studies have been done on micropropagation using plant growth-promoting microbes (PGPMs) with *Eucalyptus* species for fast production of solid wood and pulpwood (Sourmare *et al*., 2021). However, this has not been explored with indigenous tree species, and the objective of this study was to use propagation techniques and incorporate PGPMs to evaluate the survival and growth of indigenous tree species. Overall, the purpose of this project is to highlight the potential, feasibility and challenges of indigenous forestry and how commercial forestry skills, research and development can be transferred into growing indigenous trees for commercial cultivation and community development, as well as land restoration.

Problem statement

Forestry in South Africa predominantly consists of non-indigenous trees, resulting in a dearth of indigenous timber-producing forests (Dyer *et al*., 2016). This paucity of natural resources has led to a heavy reliance on forest plantations, extensively populated by exotic species, to meet the escalating demand for timber (Dye, 2013). The historical acceleration of exotic plantation forests in response to this demand has raised significant concerns regarding their impact on water resources. Furthermore, the initial preference for exotic species for afforestation was driven by the absence of economically viable indigenous species suitable for timber production (Dyer *et al*., 2016). This preference, established in the late 19th century, has shaped afforestation practices in South Africa (Albaugh *et al*., 2013) and regulatory measures on water-use and expansion of exotic plantations have been instituted for decades to mitigate potential environmental repercussions such as invasion of alien species on natural land (Dye, 2013).

Indigenous communities, who are the custodians of ancestral lands, often battle a myriad of issues, including the encroachment of commercial exotic species into natural forests which can result in the degradation of these lands (Benett and Kruger, 2013). These species become invasive and tend to overshadow indigenous vegetation further exacerbating ecological imbalances (Potgieter *et al*., 2014). With an increasing number of studies emphasizing the restructuring of ecological compositions at various scales due to invasive alien species, it has become imperative to re-evaluate the existing forestry paradigm (Benett and Kruger, 2013; Kumschick *et al*., 2015; Rai, 2015). For over a decade now the country has taken the initiative to establish the invasive alien removal program to improve water supply and restore as well as conserve indigenous vegetation (Benett and Kruger, 2013). In addition, this initiative comes long after debates by scientists and foresters argued on assumptions regarding exotic species, that their impacts go as far as interfering with the structure and the interconnections of indigenous communities to the extent of becoming invasive. Enright (2000) asserts that alien species do not cause problems in their natural lands, but in their new environment with no natural enemies present, many become invasive and can spread aggressively.

Moreover, the growth rates of indigenous tree species are notably slower compared to commercially exotic species (Dye *et al*., 2008, 2016). Various researchers believe that the slow growth rates of indigenous species are associated with their low water use or efficiency, while there is evidence that exotic species, particularly pine, wattle, and eucalypts, exhibit higher water requirements compared to locally adapted indigenous trees (Dye *et al*., 2008). However, there has been limited research on the water-use efficiency of indigenous species, and thus, there remains a significant gap in our understanding of the water-use efficiency of indigenous species (Gush and Dye, 2008). The dearth of studies regarding this discrepancy calls for a comprehensive understanding of the water use efficiency of indigenous species, particularly in regions where commercial monocultures and clones display both rapid growth and low water consumption (Albaugh *et al*., 2013). In addition, these monocultures adopted in many exotic plantations tend to hinder the restoration of degraded lands as well as have an impact on the decrease in ecosystem services.

In light of these challenges posed by exotic species, studies can confirm indigenous species possess an advantage over commercial exotic species in productive and conducive environments while their water-use efficiency is low (Dye *et al*., 2008). This shows that the reclamation of land through indigenous forestry practices has the potential to rejuvenate local economies and empower communities by creating a holistic approach to forestry management in South Africa as well as community upliftment (Constant and Taylor, 2020; Dawson *et al*., 2021). However, research shows that indigenous trees of Southern Africa remain relatively underappreciated in the global market due to their limited contribution to regional and export trade, as they are perceived to hold minimal commercial potential (Leakey *et al*., 2022). As a result, their predominant sale remains in informal markets. In addition, the most potential with indigenous trees is associated with non-timber forest products (NTFPs) that are sold in local informal markets, where others are processed into value-added products on a small-scale basis for subsistence (Leakey *et al*., 2022). Nonetheless, there remains a diverse range of indigenous tree species that can substantially provide a source of untapped potential for forestry, food, and ecology.

Purpose of the study

Indigenous forests in South Africa may cover a relatively small area but they offer a wide range of benefits, including natural resources, biodiversity, building materials, traditional medicines, and fruits (Gush *et al*., 2008). They have demonstrated their ability to use water efficiently and sparingly, hence they could highlight their viability as a compelling alternative for forestry, especially in water-scarce catchment areas (Gush *et al*., 2008). In addition, they have augmented the dietary intake of rural households, offering crucial micronutrients, antioxidants, polyphenols, and health advantages (Leakey *et al*., 2022). Also, they function as an income substitute for cash and trade, especially in periods of food insecurity and economic adversity. Hence, they hold a significant role in diminishing the susceptibility of rural families in Southern Africa to both hunger and impoverishment as well as food insecurity (Sardeshpande and Shackleton, 2019; Leakey *et al*., 2022).

Over the years, active approaches have been initiated to support food security in disadvantaged communities against the norms of planting developed commercial exotic species for timber and fruits, into expanding the cultivation of indigenous tree species for commercial timber and food (Leakey *et al*., 2022 citing Marunda *et al*., 2020). In many countries including South Africa, the clearing of natural land for commercial forestry and agriculture has led to the reduction of indigenous tree availability and germplasm (Simelane, 2009; Leakey *et al*., 2022). Thus, it is ideal to adopt incentives that encourage the cultivation and integration of indigenous tree species into forestry and farming systems for sustainable use, to minimize such situations (Leakey *et al*., 2012; 2020). This is asserted by a study that identified various tree species indigenous to Southern Africa, to have untapped potential to be integrated into forestry, food, and ecology systems (Omotayo and Aremu, 2020). These species include *D. caffra*, *Ximenia caffra, Canthium inerme, S. birrea*, *S. spinosa, B.zeyheri,* and *V. infausta, H. caffrum* etc. (Nkosi *et al*., 2020; Omotayo and Aremu, 2020; Sardeshpande *et al*., 2023).

Many of these indigenous tree species can be cultivated and incorporated into forestry for commercial purposes through resource extraction and this idea has not been explored in South Africa. Hence the current study looks to investigate the gap between indigenous commercial forestry and rural development, relating to the potential to provide benefits to local community development. The cultivation of various indigenous tree species will be important in improving rural food security (Mabhaudhi *et al*. 2016; Thammanu *et al*., 2021), contributing to local community nutrition through the promotion of underutilized tree crops, as well as meeting local socio-economic and environmental needs (Mabhaudhi *et al*. 2016; Omotayo and Aremu, 2020).

Additionally, the adoption of indigenous trees in small-scale forestry and horticulture can be implemented through the transfer of commercial forestry skills and knowledge, as a strategy to combat the challenges being faced due to climate change. This is because indigenous species are inherently adapted to local environmental conditions, thus conferring a balanced resilience against climatic stressors and natural habitat loss (Chazdon and Guarigauata, 2016; Fandohan, 2016; Mabhaudhi *et al*. 2016).

Furthermore, indigenous trees can contribute to ecological support and biodiversity conservation (Akinola *et al*., 2020). So, the restoration of degraded lands as well as the promotion of indigenous trees, contributes to the re-establishment of a balanced ecosystem by promoting resilience through habitat provision supporting various flora and fauna species (Chazdon and Guarigauata, 2016). In addition, the study's significance lies in its capacity to promote ecological integrity, community well-being, and economic advantages. Overall, it can serve as a blueprint for similar initiatives and can be applied in various contexts advocating for a more inclusive, ecologically sound, and sustainable approach in the forestry sector.

Aims and objectives of the study

The main aim of the project was to investigate the use of indigenous trees for commercial forestry, community development, as well as land restoration. This aim was achieved by assessing and evaluating the growth and survival of indigenous species through the application of propagation methods and the integration of PGPMs. This was followed by assessing ecological benefits of indigenous trees such as biodiversity conservation, soil nutrient analysis, and evaluating cost-effective methods and market potential for indigenous tree propagation, as well as the recovery of trees in anthropogenic soils.

The above aim was further achieved by the following objectives:

Objective 1

To conduct a literature search and then document existing scientific literature on the use of indigenous trees in forestry as a build-up source for the literature review. The literature review was driven by the hypothesis that indigenous forestry is viable in South Africa. It covers indigenous commercial forestry globally and in South Africa, its distribution and size, and other aspects of indigenous commercial forestry potential in terms of exploring the available forest products (wood and non-wood products).

Research question: What is the current state of knowledge on the viability of indigenous forestry in South Africa, and how does it compare to global practices in terms of distribution, size, and the potential for commercial products?

Objective 2

To conduct a social study evaluating the indigenous knowledge of selected communities to assess their knowledge of indigenous tree species in terms of importance and utilization.

Research question: How do rural and peri-urban communities perceive and utilize indigenous tree species, and what is the extent of their traditional knowledge regarding the importance and use of these species?

Objective 3

To conduct a basic growth trial using commercial forestry skills and approaches. A field trial was established using forestry techniques to conduct the trial, at a community nursery in the Ntshongweni area. Variables such as height and root collar diameter (RCD) were measured to evaluate the growth and performance of the trees.

Research question: How do indigenous tree species perform in terms of growth metrics such as height and root collar diameter when cultivated using commercial forestry techniques under field conditions, and what is the impact of *Trichoderma asperellum* on their growth?

Objective 4

To conduct a pot trial of indigenous vs commercial exotic tree varieties under greenhouse conditions using soils collected from degraded land, i.e., land on the outskirts of Pietermaritzburg or eThekwini that has been over-grazed, eroded, or colonized by invasive species or was previously a sugarcane cultivated field. A biological control agent, *Trichoderma asperellum,* was incorporated in this study and its effects on growth i.e., height and root collar diameter.

Research question: How do indigenous tree species compare to commercial exotic tree varieties in terms of growth (height and root collar diameter) under greenhouse conditions using degraded soils, and what is the impact of *Trichoderma asperellum* on their growth?

Objective 5

To explore cost-effective methods for propagating indigenous trees through the production of seedlings. While recognizing the significant challenge of tree seedling provision in commercia forestry, a propagation experiment was conducted using indigenous trees cuttings. In addition, a community survey was conducted within rural communities and among indigenous tree/plant propagators (Treepreneurs) to gather information and traditional propagation methods and associated challenges.

Research question: What are the most cost-effective methods for propagating indigenous tree seedlings, and what traditional propagation techniques and challenges are reported by rural communities?

This research endeavors to expand our knowledge of forestry, food, and ecology; it aims to provide a scientific basis for the promotion of indigenous forestry as a means of community upliftment and land restoration, ultimately contributing to a more sustainable and balanced forestry ecosystem. This investigation will not only address the ecological concerns but will also pave the way for fostering community development through the sustainable management of indigenous forests.

Thesis format

This dissertation consists of 5 chapters and the referencing system employed follows Harvard referencing style, and it aligns with the style used in the journal Florida Entomologist (Florida Entomological Society). The thesis is organized into distinct research chapters, each formatted as a stand-alone research paper. This format is predominantly used by the University of KwaZulu-Natal as it simplifies the process of publishing research derived from a thesis compared to the traditional monograph format. Consequently, there is some unavoidable repetition of references and introductory information across chapters.

An introductory section, introduces the main topic, problem statement, aims and objectives, as well as the purpose or significance of this study. The project explores the use and development of indigenous trees for commercial cultivation, mainly for timber and fruit production purposes, as well as conservation and restoration of degraded lands, and other value chains.

Chapter 1 is a review of the feasibility of indigenous forestry in South Africa, discussing the relationship between people and natural resources. The use of indigenous trees is explored through a literature search, looking at indigenous commercial forestry at a global and local scale in attempts to find the gap between the current mainstream forestry industry and sustainable rural economic growth.

Chapter 2 is a social study evaluating the indigenous knowledge of selected communities to assess their knowledge of indigenous tree species in terms of importance and utilization. This study was conducted using focus group discussions, semi-structured questionnaires, and one on-one interviews with local tree framers and Treepreneurs from local communities.

Chapter 3 is a field and growth trial of indigenous tree species established to assess and evaluate different parameters like survival rate, mean growth, RCD and height. It also reports on challenges field experiments encounter during the period of study.

Chapter 4 is a pot trial study conducted under greenhouse conditions, which discusses two aspects; the use of indigenous trees in land restoration and the incorporation of biological control agents in soil from degraded land.

Chapter 5 is a propagation study looking at the propagation of indigenous tree species from cuttings, to optimize cultivation and increase the productivity of seedlings and cuttings of the selected indigenous species. The chapter explores the utilization of indigenous trees in seedling and cutting production as seedling provision is an issue in commercial forestry.

Lastly, a general thesis overview evaluating the major findings of the study and a way forward after completion of this study (future potential studies).

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Chapter 1

A Review of the Feasibility of Indigenous Commercial Forestry in South Africa

1.1 Introduction

Southern African forests are essential for healthy ecosystems and sustainable livelihoods, but they are also extremely vulnerable to climatic changes, particularly the accumulation of temperature and moisture deficits, as well as to other external stressors like deforestation that may interact with climatic changes (Naidoo, 2017). Forestry can be defined as the science or practice of creating, managing, using, and conserving trees, and repairing forests and their associated resources for human and environmental benefit (Banerjee *et al*, 2020). It is also the management of forested land, as well as its associated resources with the primary goal of harvesting timber and non-timber products. Furthermore, trees can be planted for conservation or socio-economic purposes (Banerjee *et al*, 2020). Approximately 60% of the world's forests, (which is about 2.4 billion ha) are used mostly to produce wood and non-wood forest products (Brack, 2018). These products include various forest resources such as timber for construction, poles, fuelwood, fodder, medicine, and other non-timber forest products (Mahonya *et al*., 2019).

All humankind depends upon forests and their biodiversity (FAO and UNEP, 2020), and over 25% of the world's population relies on forest resources for their livelihoods (FAO, 2015). Forests are important to local communities because they provide food, medicine, shelter, and employment, as well as a source of income that can contribute to alleviating poverty in rural households by providing safety nets in times of scarcity (Shackleton and Shackleton, 2006; Mahonya *et al*., 2019). There is a long history of commercial forest plantations in South Africa, dating back to their first establishment in 1875 to meet the demands for wood in the country (Dye, 2013). Forestry in South Africa is focused on commercial plantations of exotic species (*Eucalyptus, Pinus,* and *Acacia*) which are estimated to be at least 1.3 million ha, for timber and non-timber production (Xulu *et al*., 2018). These forest plantations of exotic species are harvested and processed into products such as timber, charcoal, furniture, poles, pulp, chemicals, oil, pharmaceuticals, and various other products (Clarke, 2018; Dessie, *et al*., 2019). Forestry and forest resources also include indigenous forests which cover only 0.5% of the country's land area. Although heavily utilized in the past, there is currently little commercial utilization (Mucina and Rutherford, 2006). Indigenous forests are valued more for their biodiversity, provision of ecosystem services, and recreation value.

Despite all the benefits forests provide, natural, mature, and biodiverse forests may be unsustainably exploited, although forests and forest plantations cannot yield similar benefits for people and nature. Hence it is necessary to encourage sustainable planting and harvesting (Chirwa *et al*., 2008). However, the main disadvantage of indigenous forestry is trees take longer to mature before they can be harvested, which means a delay in profits (Chirwa *et al*., 2008). Additionally, limited and poorly structured markets especially for forest resource products that are not commonly traded result in a lot of uncertainty and the sector being underestimated (Meinhold *et al*., 2022; Steel *et al*., 2022). Sustainability in natural and indigenous forestry can be promoted through capacity building in appropriate harvest methods and regimes, resource monitoring, and certification or licensing. This can be achieved through sustainable forestry management, where forest resources can still be harvested whilst maintaining a healthy functioning ecosystem to meet economic, social, and environmental goals (Dyer *et al.,* 2017). The purpose of this review is to highlight the potential of indigenous forestry for commercialization and community upliftment. Also seeks to highlight the challenges faced in indigenous forestry.

1.2 South African Forestry in Southern African and International Context

South Africa is a semi-arid environment with low mean annual rainfall (Rusere *et al*., 2019). As a result, most of the country's natural vegetation is non-woody and is poorly endowed with natural forests. Nonetheless, the country managed to develop a sustainable forestry sector of noteworthy influence based on limited resources. In the Southern Hemisphere, South Africa dominates the commercial plantation sector, and it comprises one of the oldest and third-largest plantation resource areas. However, this is not the case with natural woodlands. As a result, the country is recognized among world leaders in the management and study of commercial timber plantations.

Forest plantations in the Southern African region account for approximately 3.37 million ha of forest cover, with which half of which in South Africa (Davis, 2017; Naidoo, 2017). The remaining plantations are very small in size, privately owned, and are located in Angola, Madagascar, Malawi, Mozambique, Swaziland, the United Republic of Tanzania, and Zimbabwe (Naidoo, 2017). The majority of these plantation industries produce wood pulp and lumber for industrial uses. Reports suggest that in the SADC region, South Africa produces approximately 70% of the region's total roundwood and sawn timber (Davis, 2017; Naidoo, 2017).

1.2.1 Forestry in South Africa

Forestry is an extremely critical component of the South African economy and ecosystem. South Africa is a moderately forested country with a plantation area of about 1.4 million hectares which is approximately 1% of the total South African land area, and only 0.5% of the total land area is covered by natural forests (FSA 2016; Ledger, 2017). Mpumalanga and KwaZulu-Natal each with around 40% of the total plantation area, are the cornerstone of most of the country's commercial forestry plantations. Plenty of commercial forestry plantations can also be found across the Eastern Cape, Limpopo, and the Western Cape (Figure 1.1; Ledger, 2017). And this industry is dominated by fast-growing tree species such as pine (50%), eucalyptus (43%), and wattle (7%) (Xulu *et al*., 2018). This industry can be considered a key engine for the development of local economic growth in South Africa, particularly in rural areas where people are poverty-stricken by the lack of employment opportunities (SETA, 2014). This sector supports over 0.5 million South Africans in terms of formal and informal employment (technicians in pulp and paper, equipment operators, supervisors, logging truck drivers, foresters, silviculturists, etc.), which is about 2.4% of the country's total employment (Mudombi, 2020).

Table 1.1: Commercial forest plantations with their end products in South Africa.

Species name	Plantation size	End products
Pine	584,337 ha (50%)	Timber, Construction, furniture, pallets, pulp and paper, poles
Eucalyptus	520,745 ha (43%)	Timber, boards, furniture, poles, pulp and paper, wood chips
Wattle	82,223 ha (7%)	Tannins, charcoal, tannin extract, pulp, and paper

Source: Xulu *et al*. (2018)

The forestry industry provides a variety of wood and non-wood products, as well as social and environmental benefits such as soil, water, and biodiversity conservation. The main commercial forest products are wood and wood products, which include fuelwood and charcoal especially in developing countries (DAFF, 2016). Most of South Africa's natural forests are mainly of the woodland type and are not commercially managed because commercial forestry in the country is focused almost entirely on plantations (South Africa Study, 2014). These plantations are comprised of species such as pine, eucalyptus and wattle (Table 1.1). The commercial forest industry produces about 17 million air-dry tons of the nation's annual need for wood and fibre, contributes around 1.27% of GDP, and sequesters about 4.1 million tons of CO_2 annually, among other advantages (Ndalowa, 2014; Odebiri *et al*., 2020).

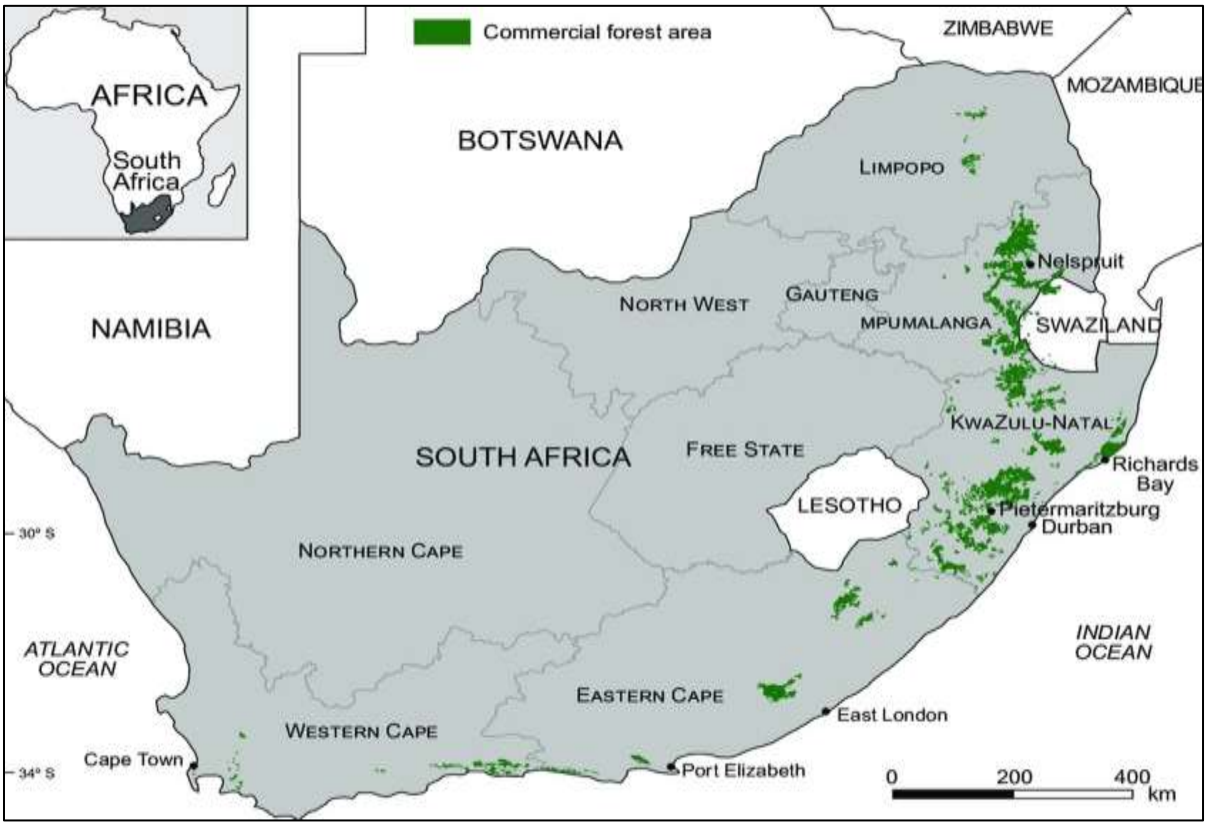

Figure 1.1: Distribution of plantation forest in South Africa (Xulu *et al*., 2018).

1.3 South African Indigenous Forestry

In the past, South Africa’s indigenous forest once played a significant role in supporting the country’s timber needs, but the volumes from these small indigenous forest areas were insufficient to fulfill growing timber and pulp needs. (Dyer *et al*, 2017). Hence, it was soon realized that the country would need to find alternative sources of timber to meet its growing demands and needs for timber. As a result, different pine and eucalyptus species were introduced in South Africa for afforestation and the country has since then become self-reliant and sufficient in its timber needs (Dyer *et al*, 2017; Xulu *et al*., 2018). Indigenous tree species harvesting has been an ongoing practice in South African forestry regions since the early 1650s (Ella, 2005). Over the years, there has been increasing interest in establishing indigenous forest plantations but never as an alternative to the fast-growing commercial exotic species, and their success was considered diminished because they were never managed, and most were eventually felled and replaced (Dyer *et al*, 2017).

1.3.1 Indigenous Forests in South Africa

Indigenous forests, exclusive of woodlands (shrubs and savannah) have a limited distribution in South Africa and occupy less than one percent of the total land surface area of the country (Leaver and Cherry, 2020). They are considered a limited resource and are regarded as one of the most vulnerable vegetation types. Despite having limited resources and low potential commercial use, they were and still are used by the local community before European arrival in the country (Dyer *et al*, 2017). They play a significant role as a timber resource in the early history of South Africa and were considered of paramount ecological importance, and in contributing towards biodiversity conservation. It is believed that their distribution reflects their bio-physical limit (Lawes *et al.*, 2004). It is suggested that even in the absence of human influence, its distribution would not extend beyond its current state, but would be/is restricted by rainfall and fires (Lawes *et al.*, 2004). South Africa's forests are broadly classified as Afromontane and coastal indigenous forests (Hayward *et al.*, 2005). They are distributed along the Cape peninsula eastward through the Outeniqua and Tsitsikamma Mountains of the southern Cape to the midlands of the Eastern Cape and KwaZulu-Natal. Some are distributed northwards along the Drakensberg Mountains of KwaZulu-Natal, the eastern Free State, Mpumalanga, and into Limpopo Province, with the northern-most forests located in the Soutpansberg Mountains (Mucina *et al.,* 2003; Lawes *et al.*, 2004).

1.4 Natural and Indigenous Forestry Product Development for Community Benefits

1.4.1 Potential of Indigenous Fruit Tree for Forestry

Globally, the human population is growing at a rapid rate, and it is expected to be over 9 billion by 2050 (van Rayne *et al.*, 2021). In Africa, growth and development will continue to place pressure on the food system, which will then drive up the demand for food production. This pressure may however be reduced by exploiting underutilized edible fruit species as substitutes or food supplements (Omotayo and Aremu, 2020; van Rayne *et al.*, 2021). Southern Africa has an abundance of edible fruit resources from indigenous tree species, which can be integrated with current food systems in combating food and nutritional insecurity (Omotayo and Aremu, 2020).

Indigenous fruit tree species (IFTs) are fruit-bearing trees that grow naturally in a particular area and are often distinguished by limited development in comparison to their potential (Mabhaudhi *et al.* 2017). In that sense, South Africa offers a wide variety of plant species and many hotspots, including Maputaland and Pondoland Albany (Nkosi *et al*., 2020), and some of these plant endemism hotspots have a wide variety of IFTs with the potential to be profitable food crops. The utilization of these species as a food source in certain rural areas such as Mpumalanga of South Africa is well documented (Shackleton *et al*., 2000; Nkosi *et al*., 2020). Despite their potential to provide for food security, many of these species are nevertheless exploited from the wild (Sardeshpande and Shackleton, 2019; 2020). Therefore, the aim should be to prioritize, introduce, and make them available to small-scale farmers to ensure that they contribute to food and income security (Nkosi *et al*., 2020).

Indigenous fruit tree species (IFTs) can play a crucial role in poverty alleviation and as a source of food in South Africa (Shackleton and Shackleton, 2004). Many rural households rely on indigenous fruit trees as sources of cash and subsistence in the Southern Africa Development Community (SADC), but until recently there has been little effort to cultivate, improve or add value to these fruits (Akannifesi *et al*., 2006; Akannifesi *et al*., 2009). These species are still currently underutilized and are also taken from the wild despite having nutrient-rich edible fruits that are also processed into food products like jams and jellies (Nkosi *et al*., 2020). According to a scorecard assessment study by Nkosi *et al* (2020), priority indigenous fruit trees such as *S. spinosa, Garcinia livingstonei, Englerophytum magalismontanum, S. birrea, D. caffra, V. infausta* and *B. zeyheri,* are all eligible for domestication programmes in northern KwaZulu-Natal.

There has been a growing interest in natural fruits within the fruit industry in Southern Africa, especially in *S. birrea* which produces fruit that is processed to make 'Amarula cream' liqueur, which is commercially sold internationally, and commercial marula beer (Mng'omba and Sileshi, 2015; Mphephu, 2017). However, this market rarely expands beyond South Africa, and farmers in other countries are yet to tap into market opportunities for *S. birrea* (Akannifesi *et al*., 2009). A review study on markets and commercialisation of indigenous fruit products in Southern Africa gives an overview of the situation although, since then there has been limited market research hence indigenous fruits have not penetrated the global markets for higher income (Akannifesi *et al*., 2009). However, research on the development of IFTs, especially *S. birrea,* has been done in countries like Malawi, Zimbabwe, and South Africa (Akannifesi *et* *al*., 2008a). Inadequate consistency in supply and quality also poses potential market limitations that domestication should address. Farmers must have access to superior stocks if they must capitalize on the benefit of domestication (Akannifesi *et al*., 2009). Even if fruits are available in the wild, the improvement of IFTs is important because this will create an incentive for their cultivation by farmers and plenty of efforts have been made to domesticate the fruit trees however, only little has been done to improve indigenous fruit trees in southern Africa.

1.4.1.1 The Economic Value of Indigenous Trees

Indigenous fruit trees can contribute to the livelihood development and profitability of commercial and small-scale farmers. Indigenous fruit trade and marking do play a crucial role in the economic development of a country, despite the low level of commercial development (Omotayo and Aremu, 2020). A body of evidence suggests small-scale farmers receive substantial revenue from the sale of indigenous fruit products (juice, jellies, and, jams and seedlings) in both urban and rural markets (Omotayo and Aremu, 2020; Omotayo *et al*., 2021). Although many farmers are reluctant or rather fear the risk to cultivate indigenous fruits on a wide scale, not until the economic benefits of domesticating underutilized fruit trees are sizeable and profitable (Omotayo and Aremu, 2020). For example, more than a decade ago it was found that in Malawi, Tanzania, and Zimbabwe, the net percentage profit of indigenous fruit to approximately 30% and higher profits were reached in areas close to the markets (Akinnifesi *et al*. 2008b).

The collection of indigenous fruits is considered an efficient method, and it provides high labour returns than crop production (Akinnifesi *et al*. 2007). For instance, the average profit from collecting *Uapaca kirkiana* in Zimbabwe was \$50, whereas collecting *S. birrea* in South Africa was \$78 (Omotayo and Aremu, 2020). In South Africa, roughly about 2000 metric tons of *S. birrea* were collected by communities, which earned close to \$180,000 annually, which was 10% of the average household income in those communities (Omotayo *et al*., 2021)). In addition, a well-known southern African Natural Products Trade Association also reported that the sale of fruit tree products generated sales of \$629,500 in gross, obtained from *S. birrea* and *Adansonia digitata* L that generated \$126,420 and \$44,120, respectively (Omotayo and Aremu, 2020). According to estimates by Meinhold *et al*, (2022), baobab resources are traded for international markets in the Southern African Development Community (SADC) region at a rate of 187.5 t powder and 5.22 t oil annually, and over 300 products have been found to contain baobab on the European markets. So, according to studies in Southern Africa, improved tree yield and early fruiting of indigenous fruit trees could and will encourage the cultivation of indigenous fruit trees by farmers (Omotayo *et al*., 2021).

1.4.2 Non-Timber Forest Products Benefits

In recent decades, it has not gone unnoticed that there has been increasing interest and importance of non-timber forest products (NFTPs) that certainly contribute to livelihood development and poverty alleviation among the rural population, and this is because communities living near, or adjacent forests or forested land heavily rely on NFTPs for their livelihoods (Suleiman *et al*., 2017; Shackleton and Pullanikkatil 2018). There has been growing attention on the NFTPs which stresses that this forest product may contribute in significant ways to sustaining the livelihoods of rural communities through income generation, as sources of food, shelter, and medicine, especially in most developing countries in Africa and Asia (Suleiman *et al*., 2017; Iponga *et al*., 2018). However, the definition of NFTPs differs with every user depending on their interest and goals, with an understanding of how people use forest resources, and the emphasis is on working towards improving the value of these resources to help contribute to bettering the livelihoods of the world’s rural poor (Shackleton and Shackleton, 2006). This is because NFTPs are utilized and managed in a variety of socioeconomic and ecological environments, as some may be utilized for subsistence while others may primarily be a source of income (Shackleton and Shackleton, 2006; Mahonya *et al.,* 2019). Without dispute, NFTPs are not only just utilized to meet subsistence needs, but they are also economic resources that may be marketed and traded between various types of actors in a variety of market types and scales. In other instances, these products may serve as the foundation for a commercial enterprise with some commodities reaching high-value markets locally and internationally (Sardeshpande and Shackleton, 2019). Approximately 44% of the world's population is currently estimated to use non-timber forest products (Shackleton and de Vos, 2022). In central Africa, more than half of the NTFPs (67% of the plants and 53% of the bushmeat) are harvested and traded (Sardeshpande and Shackleton, 2019). Again

(Sardeshpande and Shackleton, 2019) reveal that when a product’s formal market value is greater than its direct use value, the trade of NTFPs can be profitable. This is evident in the case of the baobab fruit which can be sold for four times its local value (Venter and Witkowski, 2013), and also the *Phytelephas* palm fruit which can be worth up to 600 times its domestic value on the international markets (Brokamp *et al*., 2011; Sardeshpande and Shackleton, 2019). The baobab fruit tree has not been fully commercialized in Africa for years although its resource value has grown in demand driven by its cosmetic and food potential, locally and internationally. Since 2008, when the European Union approved baobab fruit pulp as a novel food ingredient, and 2009 when the Food and Drug Administration in the United States of America (USA) approved imports, baobab oil has been offered in European and US markets (Meinhold *et al*., 2022; Venter and Witkowski, 2013). Other NTFPs value chains include that of Shea butter (*Vitellaria paradoxa* C. F. Gaertn.) in Ghana (Jasaw *et al*., 2015) and Bush mango (*Irvingia gabonensis*) in Cameroon (Ingram *et al*., 2010), where the demand and international trade has led to the farming of these species (Ofundem *et al*., 2017).

1.4.2.1 Food

Forests provide food resources, and an array of food products are harvested and collected by rural communities, i.e., edible fruits, roots and tubers, wild spinach and nutritious vegetables, mushrooms, and honey (Lawes *et al*, 2004; Sardeshpande and Shackleton, 2019; Sardeshpande and Shackleton, 2020). All these kinds of foods harvested from the forests contribute to rural food security (Sardeshpande and Shackleton, 2020), in terms of providing important nutritional and dietary supplements to the staple foods of rural people (Shackleton and Shackleton, 2004). Forests offer significant health benefits to all humankind, directly or indirectly, not just those whose lives are intimately linked to forest ecosystems, but also those who live far away from forests such as in urban areas (Sardeshpande and Shackleton, 2020). They have since been recognized for their importance in food security and nutrition, although their role in human health has not been well talked about. It is important to note that there is an essential inextricable interaction between nutrition and health, where good health cannot be achieved without good nutrition and vice versa. Many forest foods have a high nutritional value and various macronutrients found in the foods are essential for human health and development thus their lack in diets may have significant health implications i.e., nutrient deficiencies, especially in children (Bvenura and Sivakumar, 2017; UNSCN, 2004). Animal-based foods from the forest are considered the best sources of micronutrients in the meat diets since most animal foods are rich in iron, zinc, and vitamin B as well as proteins and fats (Wynn Mitscherlich *et al*., 2021). However, good dietary sources of vitamins are green leafy vegetables and wild forest fruits, but these can provide nicotinic acid, especially from wild spinach: for example, wild spinach (*Pryenacantha scandebs*) in Maputaland KwaZulu-Natal (Cunninghum *et al.*, 1988; Lawes *et al.*, 2004).

The production of edible fruit by forest differs by its forest type, as Afromontane forests have very low edible fruit production as compared to Coastal lowland and dune forests since Afromontane forests are situated at mid to high altitudes, which is one of the reasons fruits are commonly harvest in sand forests Maputaland (Cunningham *et al,* 1988; Lawes *et al*, 2004). Commonly collected fruits in South Africa usually come from the following species but are not restricted to them i.e., *Manilkara discolour*, *M. concolor*, *Englerophytum natalense*, *H. caffrum,* and *S. birrea,* and many more (Table 1.2, Lawes *et al*., 2004).

Falconer (1990) and Buthelezi (2007) reported that during food shortage and drought seasons or when there are insufficient cultivated food varieties, frequent utilization of forest foods and products becomes more common. This can suggest that forest foods (products from trees, animals, herbs, and mushrooms) are sometimes essential in improving food security and through income generation, especially within rural poor commercial value in forest foods communities (Vinceti *et al*., 2013). In a study by Paumgarten and Shackleton (2009), forest food products are sold by households regularly as a means of subsistence or when needed, to supplement primary income and meet local demand, as well as cover food expenses. According to some studies, indigenous plants would sell at a higher price at supermarkets than they would in local informal markets (Chelanga, *et al*., 2013; Senyolo, *et al.*, 2014). Omotayo *et al*. (2021) then suggest that it could be that supermarkets attract more health-conscious and nutritionally aware customers who might have greater income and are prepared to pay more for these nutritional benefits. In addition, African leafy vegetables' marketing costs were estimated to be between R0.50 and R1.50/bundle, with customers paying an average of R10/bundle (Senyolo *et al*., 2019; Omotayo *et al*., 2021). Nonetheless, in South Africa, plenty of forest foods are traded in local markets, and they continue to play a significant role in conserving the local culture because there are usually no commercial alternatives of forest foods, and even if available, forest products are still preferred (Vinceti *et al*., 2013).

Table 1.2: Indigenous fruits harvested from the wild forest**.**

Scientific name	**Common name**	**Vernacular name**
Sclerocarya birrea	Marula	UmGanu
Ficus sur	Cluster fig	UmKhiwane
Harpephyllum caffrum	Wild plum	UmGwenya
Vangueria infausta	African medlar	UmViyo, umTulwa
Syzygium cordatum	Water-berry	UmDoni
Cantium inerme	Turkey-berry	UmVuthwamini
Strychnos spinose	Monkey orange	UmKwakwa
Dovyalis caffra	Kei apple	UmQokolo
Berchemia zeyheri	Pink ivory	UmNeyi, umNcaka
Ximenia caffra	Large sourplum	UmThunduluka
Phoenix reclinata	Wild date palm	ISundu
Carissa macrocarpa	Natal plum	AmaTungulu
Englerophytum magalismontunum	Transvaal milkplum	
Mimusops zeyheri	Transvaal red milkwood	

Source: Sardeshpande and Shackleton, 2020

1.4.2.2 Medicine

According to Mander and Le Breton (2006), over 80% of the world's population especially in developing countries rely on traditional medicine and herbs for their health care, however, only a few South African traditional medicinal trees have been commercially exploited (Street and Prinsloo, 2013). Indigenous trees have been used for several thousand years and forests provide an array of medicinal plants that remote communities use to supplement their income (Lawes *et al*, 2004; Williams, 2004). South Africa has been known to be one of the richest when it comes to the production of traditional medicine and herbs from indigenous trees and plants (Dzoyem *et al.*, 2013). Typical medicinal plant products are all derived from bark, roots, leaves, and fruits. An array of studies suggest that most medicinal plant products are obtained from the bark, which is one reason that trees provide most of the medicinal products traded commercially in Southern Africa (Dzoyem *et al.*, 2013; Kaoma and Shackleton, 2014; Ozioma and Chinwe, 2019). Hence, that is why medicinal tree species are among the variety of endangered tree species in this region (Botha *et al,* 2004). Williams (2004) suggests that there is a growing reliance on natural resources by rural people, which can be attested by the harvest and sales of medicinal plants as an example of how different genders from rural and impoverished backgrounds obtain sorts of income from sales and trade of forest products, such as perfumes or medicinal plants respectively (Van Wyk and Prinsloo, 2018).

Given the current economic instability and poor development in rural areas, there is a huge likelihood that the majority of rural communities will continue the utilization of traditional medicines and their associated sales and trade (Mander, 2004; Van Wyk and Prinsloo, 2018)) This is supported by a survey conducted in Durban, KwaZulu-Natal which showed that around 84% of the black population relies on both traditional and western medicines for their healthcare (Mander, 2004). In South Africa, there is increasing demand for medicinal products, and its trade is regarded as a multi-million 'hidden economy' that responds to extensive urban demand (Van Wyk and Prinsloo, 2018). The growing demand and trade of indigenous medicines demonstrate the importance of medicinal products in rural and urban economies, not only as a basic healthcare resource but also as a source of income for the rural poor (Williams, 2004). The most utilized and valued traditional medicine comes from indigenous or natural forests, and approximately 700 indigenous tree species are used for traditional medicines and are considered important in the medicinal trade in South Africa (Mander, 1998). Of all traded medicinal plant products, bark products constitute just over one-third of the products utilized in South Africa for traditional medicine (Table 1.3; Grace *et al,* 2002; Van Wyk and Prinsloo, 2018). Over 80% of the rural community in southern Africa use the bark extract of fruit trees such as *S. birrea* for the treatment of diseases such as malaria, dysentery, diarrhea, and rheumatism (Grace *et al*., 2002)

Some forest species harvested for medicinal uses have become extinct or endangered outside of protected areas such as *Siphonochilus aethiopicus* and *Warburgia salutaris* (Lawes *et al*., 2004). *Ocotea bullata, Cryptocarya* spp, and *Curtis dentate* are other tree species that have been heavily exploited for their bark in southern KwaZulu-Natal (Lawes *et al*., 2004). Lawes *et al* (2004) state that heavy harvesting and debarking of target trees causes high mortality and tree bark damage. However, conservative, and non-destructive harvesting, or substituting bark with leaves can constitute sustainable use, e.g., in the case of *O. bullata* where in the Southern Cape (Van Wyk and Prinsloo, 2017). In response to that, gatherers are to practice high-value tree conservation whilst practicing sustainable harvesting and substituting bark with leaves of the same tree. In that case, *O. bullata* fresh leaves were tested and found to have superior pharmacological properties to those of the bark (Zschocke *et al,* 2000).

Table 1.3: South African indigenous tree species used medicinally and the alternative uses of those species.

Species	Plant part used	Alternative uses
Vachelia karroo	Bark	The bark as tannins and for rope making
Acacia xanthophloea	Bark	Wood for carpentry
Dalbergia melanoxylon	Roots	The wood is used for ornament production, walking sticks, and musical instruments.
Dombeya rotundifolia	Wood, bark, and roots	The wood used for ornament production; bark for rope making
Ekebergia capensis	Roots, bark, and leaves	The wood used for furniture
Elaeodendron metabelicum	Bark	The root bark can be used as a yellow dye and the wood can be used for carvings
Myrsine melanophoeos	Bark	The wood is used for making violins and superior furniture.
Albizia suluensis	Bark	The wood is used for timber, furniture, and firewood

Source: Van Wyk and Prinsloo, 2018

1.4.2.3 Wood carving

There has been a notable increase over the years in South Africa's wood carving industry, as well as an increase in tourism since the lifting of trade restrictions following political changes. While South Africa is a small producer of wood carving, imports tend to dominate the industry market (Mikolo, 2007; Shackleton and Shackleton, 2004b), and in 1995 imports were dominated by 19 African nations, including Malawi which accounted for 620 tonnes while South Africa accounted for about 300 tonnes (Steenkamp, 1999). Wood carving is another important industry towards the informal sector, heavily reliant on tourism while also supporting the livelihoods of numerous migrant populations (Chirwa *et al,* 2009). The wood carving sector is regarded as the cornerstone for tourism growth since it attracts both local and international tourists. According to a study by Mikolo *et al*, (2008), most wood-carving items in the Cape Town area of the Western Cape province of South Africa came from the Miombo area of SADC, with Malawi (36%) and Zimbabwe (30%) being the primary sources of the wooden crafts curio.

In many parts of the country of South Africa, several forests and woodlands provide favoured hardwood species for the diversity of raw materials to produce handicrafts, wood carvings, and household items, i.e., spoons, bowls, walking sticks, mortars and pestles, agricultural implements, and drums (Shackleton and Shackleton, 2004b). This industry forms part of a significant local economy that contributes to the development of rural livelihoods, in regions such as Zululand, Maputaland, Mpumalanga, and Limpopo region (Lawes *et al*, 2004). Most of the wood used for carving is harvested from indigenous forests, with *Ziziphus mucronata* being the most harvested species (Nomtshongwane, 1999). More wood carving i.e., wooden spoons, handles for hoes and axes, knobkerries, and traditional sticks are produced especially in southern Drakensberg, however, there is little or no local market for handcraft and carvings since the collection of wood for carving is infrequent (Lawes *et al,* 2004). In addition, this industry is relatively small in South Africa as compared to other African countries which can be a result of the limited distribution of suitable indigenous species for carving and the lack of pronounced tradition for carvings (Shackleton and Shackleton, 2004b). Although there are a few indigenous species that are usually used for carving and that includes, including *Millettia grandis*, *Pterocarpus angelonsis, Englerophytum natalense,* and *Strychnops henningsii*.

1.4.2.4 Firewood

There is limited information and documentation when it comes to firewood consumption in rural areas hence estimates are often dependent on restricted locally specific household surveys, although many rural communities use firewood and charcoal as their source of fuelwood. In general, rural communities utilize and consume more firewood as compared to urban households, although for charcoal the opposite is true (Malimbwi *et al*, 2010; Lawes *et al*, 2004). In most developing countries especially in Africa, fuelwood is seen to be the primary source of energy, and many households use wood for fuel on a day-to-day basis (Shackleton *et al*, 2004). Dovie *et al,* (2004) reported that fuelwood harvested from forests and marginal lands is believed to meet over 70% of India's energy needs. As in other parts of Southern Africa, traditionally fuelwood is South Africa mainly utilized for cooking, heating, and lighting. Even though the electricity supply has been improving since 1994, fuelwood remains the dominant source of energy for rural communities (Dyer, 1996). Firewood utilized in rural areas, except for wood deficit areas, is derived from dead wood or wood cut for other uses and hence represents a forest product. In contrast, Malimbwi *et al*, (2010) assert that firewood and charcoal used in urban areas, on the other hand, are primarily made from wood harvested for urban markets.

Studies have been carried out to document fuelwood use in South Africa (Dyer, 1996; Dovie *et al*, 2004; Shackleton *et al,* 2004), and about 59 different indigenous woody tree species used for fuel were documented. Within specific regions, different communities may use various species for fuel, even though the communities prefer utilizing indigenous species but if no alternative indigenous species are available, they, however, will use introduced (exotic) species. Hardwoods are the most preferred because they burn longer, and yield more heat with less smoke emitted, and typical species include *Acacia* and *Combretum* (Dyer, 1996). Shackleton *et al* (2004) point out that even if there are many preferred species for fuelwood, one of the reasons that hinder the success of many woodlots and plantations in Southern Africa is that planted species (mainly *Eucalyptus* spp.) are not extensively considered amongst preferred fuelwood species.

While most households and communities in Southern Africa rely on fuelwood for domestic use, there has been growing evidence that fuelwood offers the potential to generate additional income for many impoverished households (Shackleton *et al.*, 2004; Malimbwi *et al*, 2010). Generally, fuelwood collectors usually gather and collect their required wood from remote areas around their villages. In cases of fuelwood scarcity, locally, they then either travel distances to harvest wood or rather purchase from vendors. And sometimes if a thriving fuelwood market exists, this activity then becomes their mainstream source of income.

1.5 Natural and Indigenous Plantation Forestry for Biodiversity

Indigenous forests of South Africa are fighting a losing battle against alien invasive tree species such as pine and wattle (Rai and Singh, 2020). These tree species will often escape their designated forestry plantation or are purposefully planted within indigenous forests, where they then establish and colonize the indigenous forests by altering the soil, water, and light conditions, and outcompete local species (Rai and Singh, 2020; Shackleton and Shackleton, 2018). Additionally, alien invasive can and tend to consume more water than indigenous tree species, therefore it is preferable to use hardy indigenous tree species for conservation and reforestation efforts rather than utilizing fast-growing alien species (Shackleton and Shackleton, 2018). In the case of many developing countries as well as South Africa, forest management can aim to balance resource use and ecological integrity of indigenous forests to conserve biodiversity and provide ecosystem service, particularly carbon sequestration (Leaver and Cherry, 2020).

Indigenous forestry and forest plantations can be established in this case to counteract the spread and domination of various alien species. This is because numerous alien species remain confined to areas of land transformed by agriculture, timber plantations, and urban development. Many alien plants have become invasive, and Van Wilgen *et al*. (2020) reported that the greatest effects on wetter biomes (Indian Ocean Coastal Belt, Savanna, Grassland) and riparian habitats have been caused by invasive alien plants. Most invasive alien species constitute trees and shrubs in all biomes except the Nama-Karoo, which is mostly succulent shrubs, although many invasive species were introduced for a specific purpose (Richardson *et al*., 2020). However, Due to their greater growth forms than indigenous plants, several invasive alien species in South Africa have altered the structure of the vegetation (O'Connor *et al*., 2020), negatively impacting grazing potential, nutrient cycles, fire regimes and water availability (Richardson and van Wilgen, 2004). For instance, residents in Ethiopia, Kenya, South Africa, and many other places are protesting about the negative effects of *Prosopis* which has led to the extinction of some indigenous species and has caused a detrimental effect on livestock health (Shackleton and Shackleton, 2018). Unfortunately, locals in Kenya are being forced to depend more on this tree because of the negative effects of this genus, which has given them a false impression of its importance (Shackleton and Shackleton, 2018). This is mainly because *Prosopis* is considered important in charcoal making, a source of building materials, and fencing, as well as its utilization as animal fodder (Maundu *et al*., 2009). Evidence from a study by Maundu *et al*. (2009) shows that *Prosopis* is highly invasive, aggressive, and hard to control once it has established itself on land. Due to its spread, paths, homes, irrigation systems, farms, and pastureland were being severely encroached upon, which impacted negatively on biological diversity and rural livelihoods (Maundu *et al*., 2009).

In addition, due to the perceived detrimental effects on ecosystem services and biodiversity, many invasive alien plant species are the subject of costly management initiatives in South Africa where they significantly alter the ecosystem (Shackleton and Shackleton, 2018). In that case, local and hardy indigenous species for forest plantations require less expensive management operations as they are locally adapted and can play a significant role in the ecosystem and biodiversity conservation (Leaver and Cherry, 2020). Therefore, every tropical continent should be implementing extensive indigenous tree planting as a result of awareness of restoring forests, thus reducing poverty, reducing biodiversity loss, and combating climate change though carbon sequestration (Di Sacco *et al.*, 2021). However, forest restoration based on natural regeneration is considered less costly than tree planting even though its success most likely depends on soil degradation and the presence of forest vegetation.

1.5.1 Ecological and Ecosystem Benefits

Forests offer numerous ecological functions and services essential to human welfare and maintaining terrestrial systems (Kalaba *et al.*, 2013). These functions contribute significant support in the provision of products and services needed to sustain human populations (Reed *et al.*, 2017). These functions have been called by different names throughout history but have gained global attention as ‘ecosystem services’ since the late 90s, Daily (1997) reported. Although they are often confused even though they are different in definition, ecosystem functions are ecosystem-centered defined as the ecological mechanism that maintains the ecosystem, and ecosystem services are a human-centred concept, representing the contribution ecosystem makes to human well-being (Brockerhorff *et al.* 2017).

Tree species are the main key contributors to ecosystem services (ESs) because they provide goods and products. So, these services represent a human-centered understanding of the value derived from nature, which can be divided into four categories i.e. provisioning services (e.g. timber and non-timber forest products, firewood, pulp or fodder, fresh water and fish (Kalaba *et al.*, 2013; Castro-Díez *et al.*, 2019), regulating services (e.g. climate regulation via carbon uptake (MacDicken, 2015), water purification, nutrient and water cycling, pollination, control of flood and human disease (Sileshi *et al.*, 2007), supporting services (e.g. habitat for species, soil formation) and cultural services (e.g. tourism, aesthetic or inspiration values, recreation, spiritual religious values, knowledge systems, educational values, and inspiration) (Mason *et al.*, 2017; Mensah *et al.*, 2017).

With all these services, functions and benefits the ecosystem can provide, it is widely recognized that there is a direct positive relationship between most ecosystem services and biodiversity (Brockerhorff *et al.* 2017). In this case, focusing on functions allows scientists to better understand how changes in forest biodiversity cam influence the important ecological processes that are responsible for the health, integrity, and maintenance of forest ecosystems. This can also help forest managers or policy makers to make use of such knowledge to predict biodiversity management can impact the supply of goods and services useful to the economy and to human well-being (Brockerhorff *et al*. 2017).

Natural forests, parks and protected areas are recognized as functions and components of important cultural ecosystem services. However, these services mentioned above, are largely understudied and unexplored. The Millennium Ecosystem Assessment (MEA) describes cultural ecosystem services as “nonmaterial values and benefits people obtain from ecosystems” and these include cultural diversity and nature-based experiences (MEA, 2005; Taff *et al*., 2019). The latter is likely to promote human health and well-being, and this may be due to the idea that physical natural resources can influence affective states at different levels (Harting *et al*., 2014; Von Lindern 2015). So, actual natural resource qualities like tree shape, size, and densities or water characteristics can affect perceptions of well-being concerning those elements (Taff *et al*., 2019). According to a study by Tryvainen *et al* (2014), it was discovered an abrupt visit to forest-protected areas or woodland had the greatest restorative impact on stress alleviation, in comparison with an urban park visit. In addition, in their body of work, they demonstrated potential for improved stress reduction and mental recovery which goes in alignment with cultural ecosystem services.

Changes in land use can also significantly disrupt ecosystem processes and landscape patterns, which may well threaten the availability of ES (Lawler *et al*., 2014). This is particularly relevant in local narratives as exotic plantations feature in land displacement, forest degradation and loss of ecosystem services (water quality, availability, and food security), as well as erosion (Constant and Taylor, 2020). For instance, in relatively infertile soils of some areas in the fynbos of South Africa, the increase in nitrogen in the soil caused by the introduction of Nitrogen fixing exotic tree species is/has affected various ecosystem services, including soil fertility and water availability and disruption of ecosystem, functioning (Castro-Díez *et al*., 2019). Thus, it is important to emphasize ecosystem services in environmental policies without overlooking the fundamental value of nature and leaving biodiversity under protected (Dee *et al*., 2017; Silvertown, 2015).

1.5.2 Carbon Sequestration and Climate Change Mitigation

Forests and trees are essential in climate change mitigation by capturing carbon dioxide through photosynthesis and storage of carbon within forest biomass, soils, roots, branches, and leaves. Additionally, forests act as a source of oxygen and can help increase the amount of organic matter in the soil through the reduction and capturing of carbon in the atmosphere. So, this process is known as carbon sequestration, one of the most effective ways described to mitigate climate change. To achieve this, various strategies have been discussed, including afforestation and reforestation (Fawzy *et al*., 2020; Di Sacco *et al*., 2021).

Forest plantations and restoring degraded ones can increase the quantity of carbon stored in trees and soils (Fawzy *et al*., 2020), and the success of such efforts may vastly depend on a variety of variables, including site and species selection, as well as adequate management practices (Di sacco *et al*., 2021). In this sense, it is important to protect and conserve forests from deforestation and degradation to combat carbon emissions being realised into the atmosphere, as well as an act of biodiversity and ecosystem conservation (Di sacco *et al*., 2021). Sustainable forest management can help reduce greenhouse gas emissions from unregulated tree cutting i.e., deforestation, logging, and fuelwood collection, whilst preserving the capacity of forests to store carbon (Maxwell *et al*., 2019; Di sacco *et al*., 2021). In addition, forests are a significant long-term carbon sink because of their intricate structures, large trees, and relatively high resistance to fire, drought, and tolerance to frost and storm (Maxwell *et al*., 2019).

Forests in Africa, the Knysna and Amatole Mountain forests, absorb and store up to 180 metric tons of carbon per hectare per year at higher elevations. According to carbon dioxide research based on the African Climate Reality Sink, the report found that the mangrove forests within the Nxaxo Estuary on the Eastern Cape’s coast store an average of 235 metric tons of carbon annually per hectare (Akhand *et al*., 2022). Nonetheless, increasing indigenous forest plantations can be vital in biodiversity conservation and carbon sequestration. This can be achieved by burning forestry waste i.e., pruned material as a substitute to fossil fuels, soil erosion could be minimized at harvest, and forest fires will be minimized and regulated.

1.6 Barriers and Challenges of Indigenous Forestry in South Africa

Globally, indigenous tree species constitute important biological resources through the production of indigenous fruit trees in many agroecological and forest ecosystems (Awodoyin *et al*., 2015). Numerous indigenous tree species provide fruits rich in essential nutrients, and health benefits from medicine for animal and human use (Omotayo and Aremu, 2020). Many of these indigenous fruit trees are valuable although their full potential has not been fully explored as they have remained of local importance. This is because indigenous forestry locally has been neglected thus the indigenous fruit trees and knowledge continued to downgrade due to dwindling cultivation and lack of research (Awodoyin *et al*., 2015). The majority of the indigenous species in Africa have not been fully developed to their full potential in terms of quality breeding and selection, production, distribution, and availability (Omotayo and Aremu, 2020).

1.6.1 Constraints to the Adoption of Indigenous Tree Species for Forestry

Several factors contribute to the poor adoption of indigenous tree species forestry, including insufficient research on commercialization of indigenous trees (Mabhaudhi *et al*., 2017), inadequate development for the improving breeding and selection methods, lack of conservation of indigenous germplasm, and lack of improved reproductive material (seeds and planting material) (Stimm *et al*., 2022). Also, the immense expansion of exotic monocultures, developed strategies for market-oriented mono-crops, land tenure insecurity, insufficient size of landholdings, as well as the exercitation of invasive alien species have constrained the adoption of indigenous forestry (Awodoyin *et al*., 2015; Lelamo, 2021). This has resulted in the displacement of indigenous species in many areas. Lelamo (2021) asserts that the use of indigenous tree species is further constrained by the lack of education on indigenous forestry and natural resources and a lack of a multidisciplinary policy approach. Negash (2021) also adds that lack of technical expertise and indigenous knowledge about the identification, collection, and germination of indigenous tree species.

Indigenous tree forestry requires stable land tenure arrangements that ensure long-term ownership of the land because insecurities related to ownership may deter people from planting confidently of forest lands (Walters *et al*., 2005). This then makes people reluctant to invest in indigenous trees if they do not have land ownership since benefits can take long to be realized. In addition, there is also lack of awareness and government support and incentives, which might deter landowners and forestry professionals from making investments in them (Sardeshpande and Shackleton, 2019). For plantations, although indigenous species are available, a greater preference is given for the selection of exotic species, the reason being there is generally a lack of adequate information, and knowledge in the propagation and silvicultural management of indigenous species (Negash, 2021). There is generally a plentiful supply of seeds of the exotic species, they are easy to handle, and fast growing and high yielding as compared to many indigenous tree species (Albaugh *et al*., 2013). This assertion is based on evidence that the majority of indigenous tree species are obtained from a natural environment which thus tends to limit their growth potential (Awodoyin *et al*., 2015). The over-reliance of the majority on various exotic species has not only overshadowed the potential indigenous trees can offer but has significantly contributed to low-income generation and rural development by local communities in most African countries (Shackleton *et al*., 2007; Rogan, 2016).

1.7 Prospects for unlocking indigenous forestry potential

The commercialization of indigenous forest tree products, including NFTPs has been widely promoted as a conservation approach, based on the hypothesis that collectors will be motivated to practice sustainable management of forests and woodlands (Dawson *et al*., 2014) Most of our local indigenous tree species have been grown and produced using conventional methods such as homestead shade trees, nursery trees in communal forests, and as stands on farms (Awodoyin *et al*., 2015). Numerous indigenous tree species are grown deliberately, but farmers and communities still lack sufficient knowledge or rather do not realize the vast benefits these trees can produce, and this is regardless of the slight margin that knows their benefits but is afraid of the risk involved (Awodoyin *et al*., 2015). Thus, knowledge and technical expertise in the propagation and management of indigenous trees are still insufficient and this limits the realization of the benefits these trees can offer. However, in forestry, the domestication of trees is very important, especially for species of commercial importance (Omotayo and Aremu, 2020). This process may involve molecular genetics technology, tree breeding, hybridization, systematic sampling, characterization of genetic variation, and silvicultural technique development (Akinyele, 2019). Therefore, the following prospects can be utilized as relevant information about unlocking the potential of indigenous trees for forestry, food and ecology.

1.7.1 Promotion of Indigenous Tree Benefits and Useful Value Chain

In South Africa, indigenous plant trade proceeds with little government intervention and inadequate documentation of benefits from products and by-products. These include health benefits from ethnomedicinal products and phytochemical extracts (Pfukwa *et al*., 2020), nutritional and dietary benefits, oils and fruits (Omotoya *et al*., 2020; Ndhlovu *et al*., 2021). However, the promotion of priority indigenous tree species can be achieved through successful domestication of the trees; as a result, their potential in local, regional, and international markets can be enhanced and thus can contribute to economy development (Leakey, 1999). So, after the successful promotion and domestication of indigenous tree species, there is potential to enhance and develop new products for humans and animals. In that case, scientists and researchers should pay more attention to the biological, phytochemical, and dietary (nutritional) content of indigenous trees (Omotoya *et al.*, 2020).

To achieve the above, a successful value chain of priority indigenous species should be promoted, and there are several factors to be considered i.e., the policymakers and local communities must be involved in raising awareness of environmental factors and conditions, improved research and innovation, addressing needs and challenges related to promoting collaboration with local communities, and integrating gender-sensitive approaches (Awatedu *et al.*, 2021; Omotayo and Aremu, 2020). Also, multiple organizations and policymakers should engage and participate in an open process to promote the usefulness and relevance of the trees (Awatedu *et al.*, 2021; Ndhlovu *et al.*, 2021). Furthermore, Indigenous forestry could greatly benefit from tapping into streamlined supply chains traditionally developed for forestry and food products to reduce wastage and optimise returns (Aworh, 2021). The key-players that make the value chain of indigenous tree species a success include policy makers and various stakeholders such as farmers, transporters, wholesalers, retailers, and consumers (Omotoya *et al.*, 2020).

It is important to note that the value chain will help in the formulation of specific policies for numerous indigenous tree species, especially fruit trees, which will significantly strengthen potential investment and encourage the allocation of resources for the advancement of research (Omotayo and Aremu, 2020). In addition, agricultural knowledge related to indigenous fruit trees is another key resource in defining the characteristics and implementing cultivation methods. In this case, local farmers and indigenous people become key players as they have the advantage of traditional expertise and knowledge on how to grow these indigenous plants under field conditions with low input costs (Omotayo and Aremu, 2020). This is because this strategy has the potential to result in low production costs for the fruits, which can generate high income and improve livelihood benefits for small-scale farmers. Lastly, Mabhaudhi *et al* (2016) note that since the value chains for indigenous fruit trees are underdeveloped, promoting certain fruits in rural areas of Africa can provide an opportunity to build autonomous ways out of poverty.

1.7.2 Tree Selection and Tree Improvement of Indigenous Germplasm

Depending on their ecological importance and the services each (exotic vs indigenous species) can provide, indigenous tree species are usually generally preferred over exotics even though they may be considered necessary in some cases (Thomas *et al*., 2014). This is based on the expectation that indigenous species are adapted to local abiotic and biotic conditions and can support biodiversity conservation and ecosystem function significantly better than exotic species. On these bases, tree species selection becomes substantial followed by the identification of planting material (Thomas *et al*., 2014). This is true because if the species selected are not locally adapted to the conditions and the planting material is not improved, consequences such as low initial survival and high mortality may be experienced before the reproductive stage (Bresnan *et al*., 1993; Thomas *et al*., 2014). However, in forestry, the improvement of tolerance to abiotic and biotic stress is considered an essential aspect of tree performance in stands established for the production of wood and fiber is (Harfouche *et al* 2014). Thus, plantation management may require increased drought, flood, or salinity tolerance to maintain acceptable survival and growth rates in an ever-changing climate and environment, (Nelson, 2022).

However, in the case of indigenous tree species especially IFTs, tree selection can also be based on preference by users, marketers and consumers, mostly because they have a broad geographical distribution, high consumer demand and good marketing potential (Akinnifesi *et al*., 2008 c). In this case, specific screening plots can be established so that farmers may identify priority species in their region, as well as conduct on farm-trials to ascertain farmers' preferred niches for indigenous tree species (Awodoyin *et al*., 2015). Scientifically planned selection and breeding programs may well be undertaken to select promising qualities such as fruit size, shape, flavour, taste and suitability which will be paramount in wine, juice and other beverage processing. This is because the quality of fruit is always a paramount objective in fruit tree improvement. In addition, traits for resistance and tolerance to biotic and abiotic stresses can be selected among other various landraces of species (Awodoyin *et al*., 2015).

Various factors can be taken into consideration in indigenous tree improvement i.e., resistant cultivars and rootstocks, graft compatibility, high yield, adaptation to various environmental conditions as well as ease of propagation. With this, in amalgamation with high-density planting systems, pruning, robust rootstock cultivars and efficient plant protection protocols, enhanced productivity can be achieved through the selection and breeding of potential cultivars that generate greater economic yield per unit area (Awodoyin *et al*., 2015).

Therefore, effective, and long-term management approaches such as the selection of resistant trees and improved silvicultural techniques could be the solution to reducing the effects of biotic and abiotic stresses such as invasive species, pests, diseases, fire, and drought (Graziosi *et al*., 2020). Furthermore, it is important to manage the resistance and tolerance of indigenous tree species to biotic and abiotic stresses (drought, disease, etc.) through establishing breeding programs to develop resistant varieties, and relevant initiatives have been put in place to conserve tree germplasm and domesticate indigenous species (Dawson *et al*., 2014; Graziosi *et al*., 2020).

1.7.3 Improved Propagation Methods

Research on tree improvement has often focused on two methods of propagation i.e., sexual, and asexual (vegetative) propagation, and usually indigenous tree species especially fruit trees are propagated vegetatively through cutting, air-layering, bud transfers or grafting (Simons and Leakey, 2004). So, vegetative propagation, which is the regeneration of specific plants from vegetative organs such as roots, stems, leaves, buds, and even single cells or tissues, is known to contribute to long-term sustainable conservation efforts for Plant Genetic Resources (PGR) (Awodoyin *et al*., 2015). The main reasons for this method include maintaining a superior genotype, problematic seed germination and storage behaviour, reducing the time until the first flowering and fruiting, managing stages of tree development, combining desirable traits from multiple genotypes into a single plant stand, and homogenizing plantations (Verheij, 2004). All these form part of the factors needed to generate, test, and select superior germplasm from wide genetic diversity in tree parental material on farms and plantations.

Despite a general dearth of knowledge about the vegetative propagation of indigenous trees in the Southern African region, priority species across the region are being propagated and cultivated with methods and ideas developed in earlier decades (Leakey *et al*., 2022). Regardless of the insufficient knowledge, these methods are still preferred to seeds because they can capture and establish fruit and tree characteristics, by conserving sexual maturity in new clonal material and as a result, small plants can flower fruit within a short period after propagation (Leakey *et al*., 2022). This then ultimately allows researchers to be able to select desirable traits present in the indigenous tree, with the ultimate goal of generating a large number of improved propagules for farmers with limited resources and a reforestation programme (Awodoyin *et al*., 2015).

Unfortunately, some indigenous tree species in the Southern African region are incompatible with vegetative propagation techniques such as stem cutting. This is very evident with *U. kirkiana, P. curatellifolia,* and *S. birrea* are difficult to propagate by stem cuttings (Awodoyin *et al*., 2015). However, an interesting study by Mngo'mba and Sileshi (2015) showed that the fruits of *U. kirkiana* vegetatively propagated by grafting and marcotting produced larger fruits in November than those from natural stands did in December. This is after a comparison was made and it showed that seeds from grafts developed faster germination than seeds from natural stands. As a result, a feasible alternative source of seed by grafting and marcotting was recommended (Mngo'mba and Sileshi, 2015; Leakey *et al*., 2022).

According to Awodoyin *et al*. (2015), and Jaenicke and Beniest (2002), the most efficient vegetative propagation methods for indigenous trees are stem or root cutting regeneration, grafting, budding Marcotting (layering) and micropropagation. Marcotting is a layering technique of vegetative propagation that involves the growth of roots induced on the stem while the stem is still attached to the parent plant (Akinyele, 2019). After successful induction, the roots are cut off and the separated rooted stem will then produce a new plant with its roots (Akinyele, 2019; Awodoyin *et al*., 2015). Marcotting, grafting, and budding have been known to induce early fruiting and tree dwarfing and can allow compacting of trees at harvest and easing of fruit collection (Akinyele, 2019). Micropropagation is a method also known as *in vitro* or tissue culture in which new plants are regenerated from a single cell of living tissue aseptically in a controlled environment. This method is very expensive but its application is justifiable with the high production of high-value trees from the limited initial plant material and it allows for the production of virus-free plant material (Awodoyin *et al*., 2015).

1.7.4 Integrated Silvicultural and Horticultural Approach

Presently, the cultivation of indigenous tree species for forestry, food, and ecology is still an unpopular investment in South Africa and neighbouring countries, in contrast to the exotic species that are preferred with numerous existing plantations (Omotayo and Aremu, 2020). To unlock the potential of indigenous tree species and develop a sustainable economy, a thorough knowledge and understanding of indigenous tree species especially fruit-producing trees is necessary to close the productivity gap in this sector. This can be achieved effectively by involving scientists and farmers in the entire process of participatory selection, nursery, propagation, nursery, tree improvement and tree establishment (Omotayo and Aremu, 2020). With this, maintenance of superior planting material would be substantial in scaling up the production level of indigenous tree species. According to Omotayo and Aremu (2020), this will shorten the time it takes to produce and distribute planting materials from local nurseries to small-scale farmers. This has been found true as reported by Akinnifesi *et al* (2006) and Leakey *et* al., (2022) that small-scale farmers and “Treepreneurs” (i.e., a colloquial term referring to people that make a living out of selling trees) in West and Southern Africa are usually tasked to produce high-quality seeds, seedlings, and vegetative propagules which they sell to communal and commercial nurseries. However, the degree to which established nurseries can be successful can be increased through training to ensure success and sustainability. This should include training of farmers on how to collect quality germplasm from superior tree sources without depleting genetic quality, the establishment and management of trees on farms, the handling of produce during harvest and postharvest, and the commercialization of germplasm and promotion of indigenous tree products (Omotayo and Aremu, 2020). In addition, silviculture is to balance and ease the objective of maintaining forest ecosystem and their functions (Akinyele, 2019), through regeneration, tree breeding, and germplasm improvement methods, protection of trees that can be a potential candidate for species in indigenous tree species plantation (Leakey *et al*., 2022).

1.8 Conclusion

In South Africa, forests and forestry provide a significant safety net and subsistence to rural poor communities. They provide a hidden economy that is generated through the use of forests and forest resources. Commercialization of indigenous forest products has been receiving attention since it has the potential to generate reasonable returns and yield forest products in demand or products viable for trade and exports, especially traditional medicines, wood carvings and food products. Over the past ten years, the World Agroforestry Centre (ICRAF) has since improved research on the cultivation and commercialization of indigenous fruit trees to primarily improve livelihoods, household income, and economic empowerment, as well as promote biodiversity conservation and sustainable resource use.

However, more research is still required to close the performance and adaptation gap between trials managed by farmers and those by researchers, to evaluate tree improvement. This is mainly because the commercialization of fresh and processed indigenous foods has had relatively limited success in formal markets, even though indigenous species products are traded in informal markets throughout the Southern African region.

In addition, advanced research on indigenous tree improvement is extensively required to promote the cultivation and commercialization of priority indigenous tree species. And one method that offers unique possibilities to forestry and agroforestry and that is yet to be fully explored in indigenous tree improvement, is genetic engineering. Integrated and collaborative approaches between forestry, agronomy and horticulture should be encouraged to ensure better progress in the cultivation and domestication of indigenous species. Lastly, proper selection of indigenous germplasm is required, as well as the development of adequate propagation methods, thus documentation of indigenous knowledge on indigenous tree species is paramount.

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Chapter Two

Indigenous Knowledge and Documentation of the Use and Importance of Indigenous Trees in the eThekwini Area of KwaZulu-Natal Province

Abstract

Indigenous trees in South Africa play a crucial role in the country's nature and culture. The intricate knowledge held by indigenous communities regarding the utilization of these trees offers unique perspectives distinct from conventional scientific viewpoints. This study addresses the inadequate documentation of indigenous knowledge on indigenous tree species, recognizing its decline as a significant challenge across the African continent, impacting cultural preservation and sustainable natural resource management. This study was carried to evaluate and report on the utilization and importance of indigenous tree species around three peri-urban communities of the eThekwini Municipality, KwaZulu-Natal. A snowball sampling strategy was used to recruit focus group participants (N=29) and a questionnaire was administered at one of the focus group discussions (N=10). A purposive sampling strategy was used to identify interviewees (N=10). The survey identified a total of 21 indigenous tree species reported across all three sites and 12 species were reported in either all three or two sites. Notably, *Sclerocarya birrea* (Marula), *Prunus africana* (Red stinkwood), *Trichilia emetica* (Natal mahogany) and *Ficus sur* (Broom Cluster fig) emerged as highly utilized species, each utilized by more than 90% of participants (n=20). Resource product utilization predominantly centered on edible fruits and medicinal applications derived from bark and leaves, constituting 60% of overall usage by participants. Treepreneurs exhibited profound knowledge on indigenous trees and showcased a dedicated commitment to propagation efforts, expressing a clear preference for indigenous species over alien invasive plants. These findings revealed that species with multiple uses were more commonly utilized as compared to species with one use, emphasizing the commercial value and economic potential. This study recommends educational and awareness programs in schools and local communities to promote the benefits of indigenous tree species, thereby fostering the well-being and development of rural, peri-urban, and urban communities. Ultimately, such initiatives contribute to the preservation of indigenous knowledge and the sustainable management of natural resources.

Keywords: Indigenous knowledge; peri-urban communities; eThekwini Municipality; treepreneurs; economic contributions; cultural preservation.

2.1 Introduction

South Africa's indigenous trees play a crucial role in the country's nature and culture (Yanou *et al*., 2023). These trees not only shape the landscape, but they are also deeply rooted in the cultural, ecological, and economic structure of the communities in which they grow (Benner *et al*., 2021). Understanding the complex structure of indigenous knowledge surrounding the use and significance of indigenous trees is critical for promoting sustainable resource management, maintaining cultural heritage, and improving biodiversity conservation (Benner *et al*., 2021; Yanou *et al*., 2023). Benner *et al*. (2021) assert that indigenous communities and local people possess a wealth of knowledge, especially considering that indigenous communities may offer distinct perspectives and interpretations that differ from various reported scientific viewpoints. Additionally, these unique perspectives are deeply rooted in traditional uses, cultural connections, and language as well as names and distinct knowledge representing local systems, hence forming an understanding that is significantly different from scientific approaches such as forestry, and natural resource management (Akinola *et al.*, 2020; Hill *et al*., 2020; Benner *et al*., 2021).

The intricate web of relationships between people, biodiversity, and their environment underscores the importance of acknowledging traditional ecological knowledge (TEK) in ongoing conservation efforts (Hill *et al*., 2020). Ethnobotanical studies that examine the dynamic interplay between indigenous communities and their surrounding biota, offer invaluable insights into ecological processes, present novel directions for conservation monitoring and evaluation, and offer substantial potential for enhancing natural resource management (Hurrell and Albuquerque, 2012). Furthermore, the integration of TEK into ecological and biological studies, strengthens the connection between human populations and their environment, substantially shedding light on the path to sustainable resource utilization (Jarić *et al*., 2020).

Plant biodiversity offers humans with four categories of ecosystem goods and services, encompassing provisioning, regulating, supporting, and cultural functions (MEA, 2003; Maroyi, 2022). Plant resources harvested from the wild serve as an important safety net and source of livelihood, particularly for impoverished individuals and those residing in marginalized areas who rely on them for food, fuelwood, medicines, and building materials (Shackleton and Shackleton, 2004; Maroyi, 2017, 2020). However, Shackleton *et al*. (2023) suggest that plant resources are not only important for the poor but also for the middle-income class and the rich. As a result, plant biodiversity is required to fulfill various human daily life demands (Maroyi, 2020).

The decline of traditional knowledge within indigenous communities in sub-Saharan Africa is described as a significant challenge for the continent, impacting the preservation of cultural traditions and achieving sustainable natural resource management (Mannet, 2011; Maroyi, 2017). Across generations, indigenous knowledge tends to decline as older members of the family pass on, and the youth migrate to urban areas (Basdew *et al*., 2017). Hence, it is important to assess and report on ethnobotanical studies conducted in an area not previously examined because of the rapid rate of acculturation and urbanization in rural South Africa (Mokgolodi *et al*., 2011). In this case, the preservation and sustainable utilization of indigenous resources can significantly enhance the basis of science for policy implementation and management of resources. For example, *Sclerocarya birrea* marula tree offers various advantages at the subsistence level with its commercial impact considering that all parts of the tree can be utilized particularly the fruits which are considered the most valuable cultural and economic resources in South Africa (Mokgolodi *et al*., 2011; Leakey *et al*., 2022). Legodi *et al*. (2020) on their review noted that there has been an increasing focus on the marula fruit which mainly involves the transition from traditional methods of making wine or Marula liquor to exploring technologies for the wine-making process and its subsequent commercialization. They add that procedures of fruit processing will end in the production of fruit peels, kernels (nuts), and juice (Legodi *et al*., 2020). Furthermore, Marula-based products are increasingly growing in the market either through rural communities or private sector companies with the primary goal of enhancing the well-being and livelihoods of those communities (Legodi *et al*., 2020; Leakey *et al*., 2022). Hence, natural resource value addition and nature-based livelihoods require preservation of TEK (Leakey *et al*., 2022).

Indigenous knowledge constitutes a vital component within communities that is carried down through generations, as is the culture of the community (Fernandez *et al*., 2021). It is defined as a body of knowledge obtained by local people through the accumulation of experiences, informal experiments, and a deep understanding of the environment within a specific culture. Hence, it is unique to a particular group, and local people who are custodians, such as elders, farmers, propagators, gardeners, traders, harvesters, and healers (Dube and Musi, 2002, Mannet, 2011; Mbongwa *et al*., 2021). According to the research, indigenous knowledge and traditions can help conserve biodiversity (Fernandez *et al*., 2021). In South Africa, there are more than 30,000 species of diverse plants typically vascular plants, and approximately 3000 of those species are utilized for medicinal purposes (van Wyk, 2008), and more than 650 are for fuel wood, construction materials, food as well as crafts (Xego *et al*., 2016). Indigenous tree species can be utilized for various reasons, and ethnobotanical studies are recognized as effective approaches in updating indigenous knowledge based on indigenous tree use and extracted products as well as identifying new products based on those plants and previous reports (Mahwasane *et al*., 2013). As a result, this study attempts to evaluate and report on indigenous tree importance and use around communities of the eThekwini Municipality. Given that eThekwini is a rapidly growing metropolitan, it is crucial to document and preserve ethnobotanical knowledge which directly correlates with improved urban outcomes, impacting areas such as health, well-being and livelihood, food and nutrition, and household economy (Leal *et al*., 2018; Chakona and Shackleton, 2019; Hare *et al*., 2021).

This study seeks to contribute to the documentation and preservation of indigenous knowledge surrounding the use and significance of indigenous trees in three peri-urban communities under the eThekwini metro, as well as to identify possible indigenous tree species for forestry based on community preferences. This was achieved by answering questions based on which indigenous tree species and products are commonly used and harvested in each study area, as well as capturing local tree species preferences. Additionally, knowledgeable participants were asked about propagation methods and challenges, objectively seeking to use this information to explore the feasibility of propagating indigenous tree species using different propagating methods for forestry.

2.2 Material and Methods

2.2.1 Study Location

The current study was carried out in three peri-urban areas that are housed within the eThekwini Metropolitan, a portion of the KwaZulu-Natal province. The eThekwini Metropolitan is home to about 3.9 million people, constituting 35% of the total population in the KwaZulu-Natal province of South Africa. Due to the impact of climate change, the metro has since embarked on establishing initiatives of reforestation and restoration of degraded forests to rehabilitate the land into indigenous forest as an approach of adaptation and mitigation efforts as well as enhancing biodiversity and ecosystem services (Douwes and Buthelezi, 2016, Moyo *et al*., 2021). The initiatives have grown to also support the well-being and livelihoods of nearby communities through the provision of natural resources and socio-economic benefits from job creation (Mugwedi *et al*., 2017; Moyo *et al*., 2021). Additionally, the reforestation initiatives have been in conjunction with the clearing of invasive alien plants that tend to hamper the restoration success of forests. Hence, this study considers three communities with involvement with restoration programs and diversity of indigenous tree species as well as indigenous knowledge of natural resources:

a. Maphephetheni community also known as Mbozamo uplands is a peri-urban area situated approximately 80 km west of Durban in the Valley of a Thousand Hills of KwaZulu-Natal. The community is surrounded by the Mqeku River to the West while to the South is the Inanda Dam, and further bordered by the Pisweni mountains to the North and the Matata plateau to the East. The Maphephetheni community is home to people who are still rooted in their cultural values which play a huge role in their livelihoods (Bhengu, 2020). Additionally, it consists of natural vegetation which they benefit from through the utilization of natural resources.
b. Ntshongweni community lies above the Ntshongweni Dam along the Mlazi River Valley, between Durban and Pietermaritzburg in South Africa's KwaZulu-Natal province. It is situated 44 km Outer west of Durban. The area consists of natural vegetation and riparian forests, although the eThekwini municipality’s EPCPD (Environmental Planning and Climate Protection Department) is actively involved in managing invasive alien species as well as running reforestation programs around the community (Sardeshpande *et al*., 2023).
c. Buffelsdraai community is situated approximately 25 km north of Durban, in the KwaZulu-Natal province of South Africa. The peri-urban area consists of the Buffelsdraai Landfill site which was formerly under sugarcane cultivation for many years in the past and now is under restoration, planted with indigenous tree species (Mugwedi *et al*., 2017; Tsvuura *et al*., 2023). While the primary goal of the reforestation program was climate change mitigation, the program has had a notable impact on biodiversity enhancement. Additionally, the initiative has concurrently improved the ecosystem functions and more importantly it has directly contributed to the development of the livelihoods of nearby local communities through job creation (Moyo *et al*., 2021). This is evident in the case of Treepreneurs from the community that have been involved in the program through the planting of indigenous tree species and trade of tree saplings for credit notes which are redeemable to purchase groceries, building materials, etc. (Douwes *et al*., 2015)

2.2.2 Sampling Strategy

The sample selection was done in two phases. The initial phase of sampling used a snowball sampling strategy to select of participants from two communities i.e., Ntshongweni and Buffelsdraai. These communities were specifically chosen based on their socio-economic differences, the opportunities available to them, and their utilization of natural resources from indigenous tree species.

In each community, community representatives were engaged with, including local chiefs and councilors, to discuss and gain their support for community involvement. These representatives were briefed on the project and requested to invite a cross-section of the community to attend focus group discussions or interviews with the researcher.

Participants were consenting adults irrespective of their gender, age, and status in the community which included community elders, traditional healers, and local farmers. Focus group discussions were held at two communities, i.e., Ntshongweni (29 participants) and Buffelsdraai (10 participants). A snowball sampling strategy was used as described above to recruit a cross section of community members through local community representatives. At the focus group discussion in Buffelsdraai, a questionnaire was also administered to all participants.

The second phase of sampling followed a purposive sampling strategy, where participants at Maphephetheni (2 interviewees), and Ntshongweni (8 interviewees) were engaged for face-to-face interviews based on their knowledge of the propagation of indigenous tree species with identifying individuals, specifically Treepreneurs or those with previous involvement in the restoration program, to participate in interviews with the researcher.

Sampling was undertaken between September 2021 and March 2022. The data collection tools and sample sizes varied across sites due to availability of participants in the wake of the pandemic.

2.2.3 Data Collection and Analysis

This study adopted a qualitative and quantitative approach, utilizing semi-structured questionnaires, focus group discussions (FGDs), and face-to-face interviews as the primary data collection tool. The semi structured questionnaires (Appendix 2C) were designed to be in a list format of indigenous tree species selected based on their prevalence in the eThekwini Municipal Area (EMA), with a scale ranging from "not used" to "mostly used.” This questionnaire was used to elicit information on the importance, uses, and most utilized indigenous tree products around EMA.

One FGD was conducted at Ntshongweni (29 participants of which 8 also interviewees, Appendix 2A), one FGD coupled with a questionnaire survey was administered in Buffelsdraai (10 participants of which 10 survey respondents, Appendix 2C), and one face-to-face interview was conducted from the Maphephetheni community (2 interviewees, Appendix 2B). The Maphephetheni interview only documented perspectives from plant propagators, also known as Treepreneurs. Quantitative data collected from the surveys were all recorded in an Excel spreadsheet and subjected to analysis for descriptive statistics.

2.3 Results

2.3.1 The importance and resource use of indigenous tree species reported at three communities under the eThekwini metro.

Participants across all three peri-urban communities indicated their knowledge and use of indigenous tree species by mentioning their most commonly utilized indigenous tree species and products or uses. A total of 21 indigenous tree species were reported in this study along with their perceived uses and harvested products across the three sites (Table 2.1). A total of 12 species were reported and utilized in either all three or two communities including species such as *Albizia adianthifolia*, *Acacia karroo*, *C. inerme*, and *H. caffrum* and only four species were used in all three communities along with their uses i.e., *S. birrea*, *V. infausta*, *T. emetica*, and *Prunus africana* (Table 2.1).

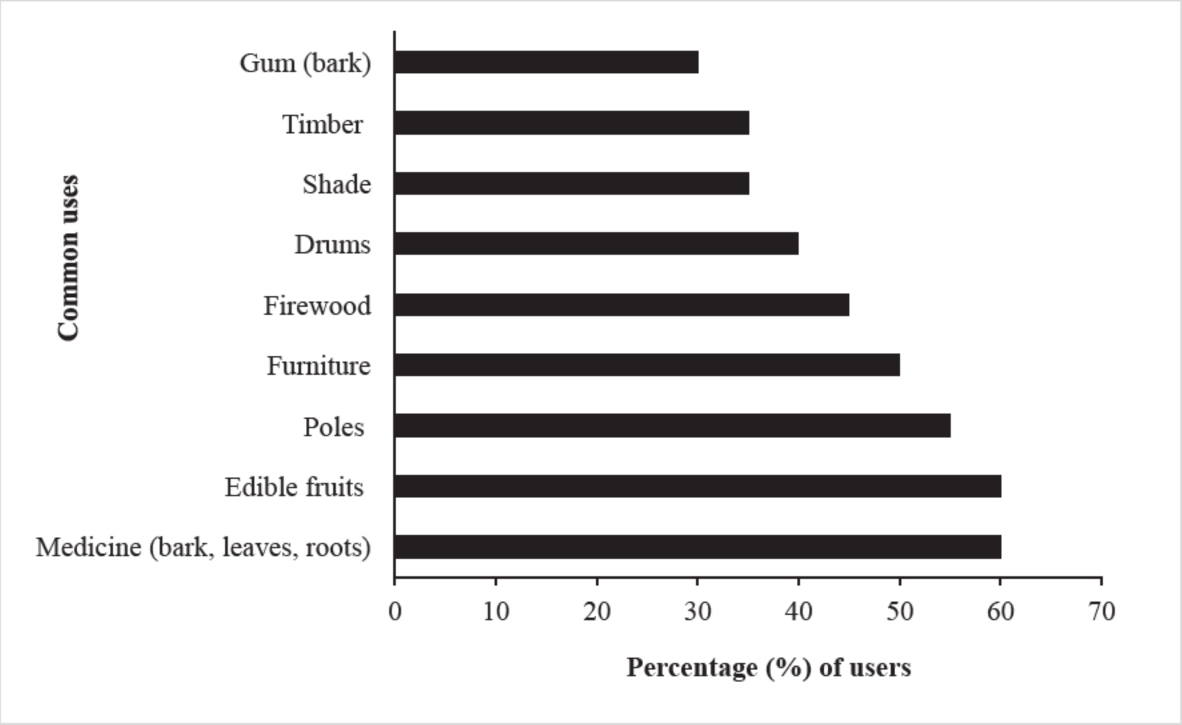

Figure 2.1: Percentage of participants reporting on the use of indigenous tree resource products at the three peri-urban sites (n=20).

Amongst the 21 species reported in this study across all three sites under investigation, only 4 species have been used by 90-95% (n=20) of participants, and three species have not been used by 90% of the participants (Figure 2.1). The species used by most participants include *S. birrea* (Marula), *Prunas africana* (Red stinkwood), *T. emetica* (Natala mahogany) and *F. sur* (Broom Cluster fig), and the species not used by many include *Vachellia sieberiana* (Paperbark thorn), and *Acokanthera oblongifolia* (African wintersweet).

The most commonly utilized species around all three communities have multiple uses and the most commonly utilized products are medicine and fruits. Figure 2.1 shows that 60% of the participants usually utilized medicinal and fruit products from indigenous tree species and only 35% utilized gum and timber harvest from the species.

Table 2.1: The use of indigenous tree species and their associated products by participants at each site, i.e., Buffelsdraai (B), Ntshongweni (N), and Maphephetheni (M). (Y = Yes, N = No)

Attributes/Purpose	Species name	Latin name	Common uses	B	N	M
Naturally occurring	White Stinkwood (uSinga lwesalukazi)	*Celtis africana*	Timber	Y	N	N
	Fever Tree (umHlosinga)	*Vachellia xanthophloea*	Medicine, timber	Y	N	N
	Red Stinkwood (iNyazangoma)	*Prunus africana*	Medicine, furniture	Y	Y	Y
	Natal Mahogany (umKhuhlu)	*Trichilia emetica*	Medicine, timber	Y	Y	Y
	Sugar bush (isiQalaba)	*Protea caffra*	Medicine	Y	Y	N
	Wild Plum (umGwenya)	*Harpephyllum caffrum*	Medicine, fruits, timber	Y	Y	N
	River Bushwillow (umDubu)	*Combretum erythrophyllum*	Medicine, poles	Y	Y	N
	Blunt-leaved current (iSihlakothi)	*Searsia rehmanniana*	Medicine	N	Y	Y
	umHlalumakhwaba		Medicine	N	N	Y
Planted	Sweet Thorn (umuNga)	*Acacia karroo*	Medicine, gum	Y	N	Y
	Paperbark thorn (umKhamba)	*Vachellia sieberiana*	Medicine	N	N	Y
	Forest silver-oak (iPhahla)	*Brachylaena discolour*	Poles, firewood	Y	N	N
	African Medlar (umTulwa)	*Vangueria infausta*	Fruits, medicine	Y	Y	Y

	Water-berry (umDoni)	*Syzygium cordatum*	Fruits, medicine	Y	N	N
	Umzimbeet (umSimbithwa)	*Millettia grandis*	Poles, firewood, furniture	Y	N	Y
Propagated in Nursery/Treeprenuers	Flat Crown (umHlandlothi)	*Albizia adianthifolia*	Medicine, shade	Y	Y	N
	Buffalo Thorn (umPafa/umLahlankosi)	*Ziziphus mucronata*	Medicine, fruits, timber	Y	N	Y
	Marula (umGanu)	*Sclerocarya birrea*	Medicine, fruits, timber	Y	Y	Y
	Turkey-berry (umVuthwamini)	*Canthium inerme*	Fruits, medicine, furniture	Y	N	Y
	African wintersweet (iNhlungunyemba)	*Acokanthera oblongifolia*	Medicine	N	N	Y
	Broom Cluster fig (umKhiwane)	*Ficus sur*	Fruits, drums	Y	Y	N

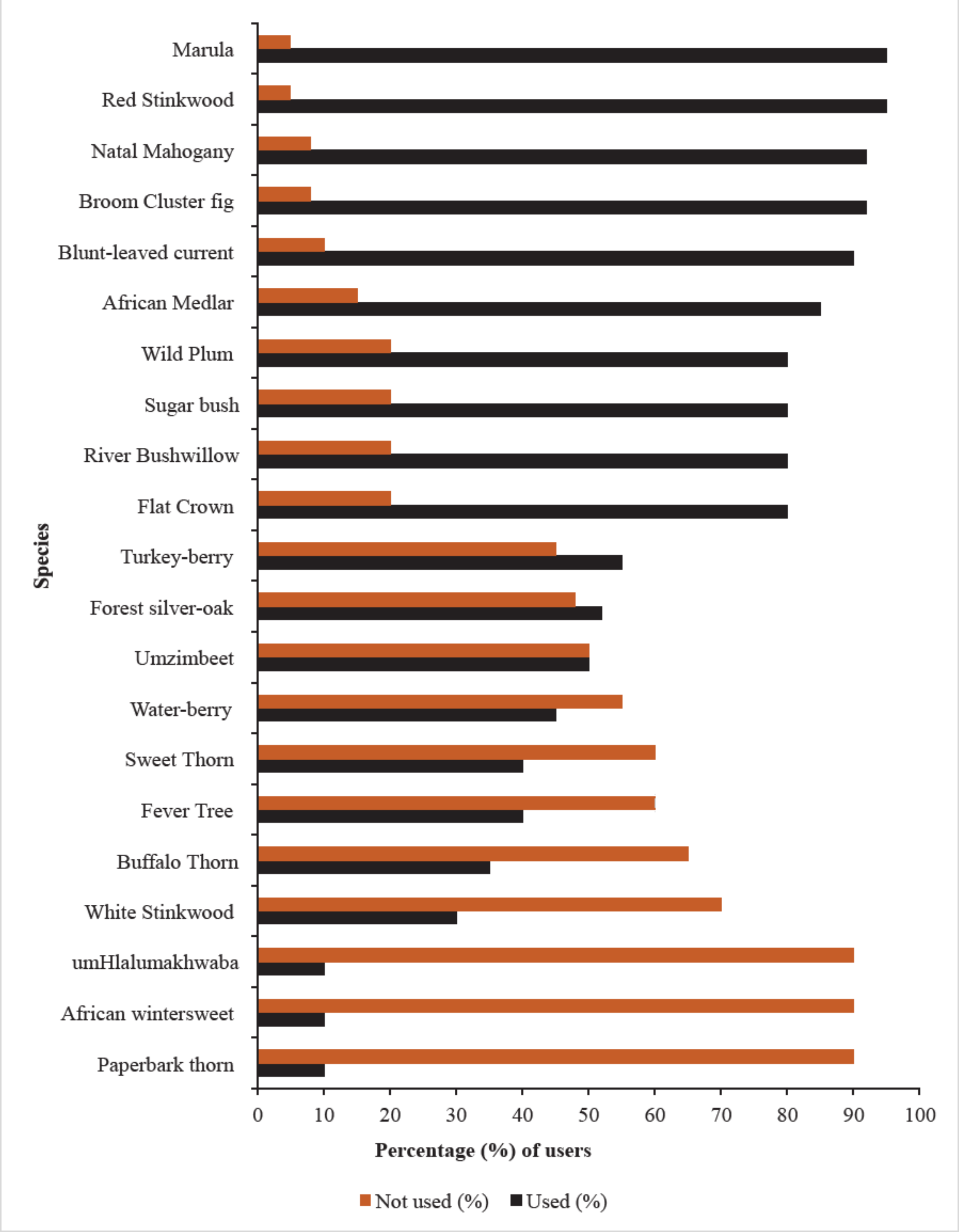

Figure 2.2: The usage of indigenous tree species in reported by participants in percentage across the three sites.

Planting and harvesting of indigenous tree species for medicinal purposes and fruits for consumption is actively undertaken across the three communities under investigation and this is evident with the number of species utilized by each community (Table 2.1). During discussions, the participants acknowledged that even though some indigenous tree species can be found around the community, most of the species are found in the nearby forests or in the wild where some herbs and medicinal extracts are harvested e.g., *Prunus Africana* (Red stinkwood) and *Protea caffra* (Sugar bush). However, some species are protected because they have a certain value to the community, either spiritual or commercial value for example *Vachellia sieberiana* (Paperbark thorn; medicinal value) and *Ziziphus mucronata* (Buffalo thorn; spiritual importance or used in death occurrences) (TP1). They added that most commercial value of indigenous tree species is from medicinal products that are extracted mostly from Paperbark thorn and Marula that are sold for medicinal purposes, which is where the market is open. Additionally, they indicated that some species are protected and were not to be cut down without valid reasons such that resource harvesting has been sustainable because the forest or most of the land is under tribal authority.

"*The trees around the community are protected and they are not supposed to be cut down with no reason".*

- TP1

"*umLahlankosi* (*Ziziphus mucronata*) *is protected, is not to be touched because it is only used for funerals".*

- TP1

2.3.2 Indigenous Tree Species Planting and Propagation

The participants also declared ecological knowledge and awareness of planting indigenous tree species to eliminate invasive alien species and noise pollution. Upon further discussion, the participants acknowledged that even though some species are known around their communities, some are very uncommon or are rare to find, therefore they would want more of those species. These species include *Celtis Africana* (White stinkwood), *Syzygium cordatum* (Water-berry), *Strychnos spinosa* (Monkey orange), and *Ximenia caffra* (Sour plum). They also declared that they prefer indigenous tree species around the community and are against the idea of planting invasive alien species because they compete with local species (TP2).

"Uncommon species around our community UmGwenya (*H. caffrum*)*, uSingalwesalukazi (Celtis Africana)".*

- TP2

"Species we would want include umDoni wehlathi (Syzygium cordatum) (for medicine and fruits), umHlali (Strychnos spinosa), and umThunduluka (Ximenia caffra) for delicious fruits (because these trees are scarce or hard to find around the community). And no to alien trees because they block our preferred trees from growing".

- *TP2*

The participants outlined that the species that they worked with or would propagate and plant during the restoration project, was from a list that was provided by the project manager of the Buffelsdraai restoration community project. The list would consist of various species that are found around the community at large and these species include *Ficus sur* (Broom cluster fig), *Sclerocarya birrea* (Marula), Acokanthera *oblongifolia* (African wintersweet), *Ziziphus mucronata* (Buffalo thorn), *Vachellia sieberiana* (Paperbark thorn) etc. So, they would get the list of the species to provide, and they then go into forests to gather seeds for propagation where they will plant the seeds in bath dishes and then at emergence stage, they would transfer them to bottles. They emphasized that the bottles need to have holes at the bottom to allow water drainage and for the tree and roots to breathe and grow well. Also, frequent watering was required for the seedling to grow well (TP1). After the seedling have grown adequately well, they would be traded for vouchers or any sort of desired material (construction or house material).

"Frequent watering is required for seedlings to emerge, and I nurture them just like a young baby".

- TP1

2.4 Discussion

Indigenous trees are known and utilized in and around the three peri-urban communities under investigation, and this study has documented indigenous tree resource use as well as the knowledge associated with them. In this study, 21 indigenous tree species were reported and used across the three communities and more than 90% of the participants used more than four species as well as three species that were not usually used by 90% of participants (n=20). On average, each of the participants used more than 10 of the reported indigenous tree species either for medicine, fruits, or poles. The findings of this study revealed that species with more than one use were the most utilized accounting for three species (*S. birrea*, *F. sur,* and *T. emetica*) as compared to species with one use (*V. sieberiana* and *A. oblongifolia*). In addition, the study further highlighted edible fruits and medicine from bark and leaves were the most utilized indigenous tree products, whereas timber and gum were least utilized, possibly due to the availability of alternative sources of timber as well as restrictions on cutting down trees (Guild and Shackleton, 2018). These findings align with some of the local studies (Mashile *et al.*, 2019; Shai *et al.*, 2020; Omotayo *et al.*, 2020a) and literature that suggests that edible fruit and medicine products from indigenous tree species are acknowledged and utilized in their daily lives as a source of livelihood (Omotayo *et al.*, 2020b). This can highlight the interest and need for tree production for indigenous fruits for consumption and medicinal properties (Akinola *et al.*, 2020; Shai *et al.*, 2020). Van Wyk and Prinsloo (2018) assert that plants are the general source of medicine globally, either traditional or Western. Additionally, the use of medicinal plants among urban, peri-urban, and rural communities plays a role in cost-saving and fostering a connection to cultural heritage, providing benefits to both physical and mental well-being (Sanchez-Badini and Innes, 2019; Konijnendijk *et al.*, 2023). Hence, concerns about deforestation may be misguided as the existing utilization of plant resources in rural, urban, and peri-urban areas appears to prioritize food, medicine, and craftsmanship (Bunge *et al.* 2019). Moreover, food acquisition from fruit is more likely to support food and nutrition security for those communities (Garekea and Shackleton, 2020; Ahmed *et al.*, 2022).

Interestingly, Marula (*S. birrea*) and Broom cluster fig (*F.* sur) species were reported as the mostly utilized species for both fruits and medicine and Natal mahogany (*T. emetica*) for medicine (Figure 2). This finding is supported by study conducted in Mpumalanga province suggesting that the reported species are the most preferred and further acknowledge that most indigenous tree species utilized for medicine are fruit-bearing trees (Mashile et al., 2019; Welcome and Van Wyk, 2019; Shai *et al.*, 2020). Nkosi *et al.* (2020) reported that Marula (*S. birrea*) is one of the highest ranked species with potential for commercialization in KwaZuluNatal and in other countries. A variety of our indigenous tree species are valued for their fruit, nutritional, commercial and ethnomedicinal contribution to society and these species include *S. birrea*, *H. caffrum*, *T. emetica*, and *F. sur* (Pfukwa *et al.*, 2020). Their byproducts are usually incorporated into medicinal remedies to combat various diseases and their ethnomedicinal applications are to act against various oxidative stresses. For example, *S. birrea* and *H. caffrum* fruits can be eaten raw, and processed into juices and liquors, and leaves and stem barks concoctions used to treat skin diseases and hypertension (Nkosi *et al.*, 2020; Pfukwa *et al.*, 2020). These findings from the survey correspond with those from the focus group discussion and interviews. During the interview, Treepreneurs revealed that *S. birrea* (Marula) and *V. sieberiana* (Paperbark thorn) are the most commercially valued indigenous trees for medicine and are usually sold or traded. This finding is further supported by literature by Cock *et al*. (2020) in the case of *V. sieberiana*, documenting traditional uses of some indigenous tree species for medicine.

In this study, Treepreneurs showed to have vast knowledge on the uses and propagation of indigenous tree species. A study by Tsvuura *et al.* (2023) supports these findings by reporting that individuals or Treepreneurs who were involved in the restoration project in Durban, working in supplying indigenous tree saplings exhibit greater knowledge of natural resource utilization by acknowledging the resources' contribution to their livelihoods. The Treepreneurs would collect propagation material such as seeds to plant in plastic bottles and then take care of their plants and nurture them until they are ready, *"Frequent watering is required for the seedling to emerge, and I nurture them just as like a young baby".* This can be explained by passionate working when it comes to indigenous tree propagation or something of value such that they further added that they always prefer indigenous species over alien invasive because alien species compete with their preferred indigenous species *"Species we would want include umDoni wehlathi (Syzygium cordatum) (for medicine and fruits), umHlali (S. spinosa), and umThunduluka (Ximenia caffra) for delicious fruits (because these trees are scarce or hard to find around the community). And no to alien trees because they block our preferred trees from growing".* This is true because invasive alien species can cause environmental damage and alter the ecosystem (Rai and Singh, 2020; Arrington, 2021).

Additionally, actively participating in environmental stewardship can be a significant way to gain and pass on ethnobotanical knowledge (Riolo, 2019). This is particularly crucial in urban environments, where both the involvement in environmental activities and the preservation of traditional knowledge are rapidly diminishing. Hence, the implication is that engaging in such efforts of caring for the environment can serve as a means to preserve and transmit valuable ethnobotanical knowledge, especially in rural, urban, and peri-urban areas facing the threat of losing such knowledge (Riolo, 2019). Moreover, the findings highlighted that indigenous tree growing and selling can be undertaken as an initiative toward contributing to one's livelihood (Tsvuura *et al*., 2023). Gerrish and Lea Watkins (2018) can attest to this with evidence suggesting that peri-urban forestry has the potential for income generation and socioeconomic contribution. Furthermore, a study by Ballamingie *et al*., (2019) suggests that communities could explore the potential of community economy through participating in the harvest of indigenous produce from peri-urban forests or urban areas even around cities. They further declare that there is a hidden economy in utilizing the fruit produce that usually goes to waste around cities, and they would do this by reserving the fruits for purposes of trade as well as to address food security (Bellamingie *et al*., 2019). Similar patterns can be followed by the Treepreneurs and other enthusiastic individuals to take part in exploring the hidden community economy.

Planting of indigenous tree species with feasible potential of generating income and benefits could be practiced around various urban areas to promote ethnobotanical knowledge of communities. Gwedla *et al.* (2022) suggest that indigenous species in urban gardens can contribute to improved human well-being and the provision of ecosystem services because gardens promote connectedness to nature and humans. The utilization of plant resources has a human-nature interaction that is still common in rural communities however, this practice should also be encouraged in urban areas to uphold the cultural heritage and their practices (Fischer and Kowarik, 2022). This practice can be encouraged in urban areas by promoting urban foraging of indigenous species. Additionally, there is a greater need to educate and raise awareness on the benefit of a greater variety of indigenous tree species even though rural and peri-urban communities actively utilize indigenous trees. This can be achieved through education, training, and awareness programs on indigenous tree utilization and their associated benefits, especially in schools or in local communities so they can take advantage of the variety of benefits indigenous tree species can offer (Lauri *et al*., 2017; Ulian *et al*., 2017). As a result, these efforts can play a huge role in contributing to the development of rural, peri-urban, and urban communities and the well-being of their livelihoods (Munien *et al*., 2015).

2.5 Conclusion

In conclusion, the study sheds light on the extensive knowledge and utilization of indigenous tree species in three peri-urban communities. Documenting the resource use and associated knowledge revealed that over 90% of participants employed more than four species, with an average use of over 10 species per participant for various purposes such as medicine, fruits, or poles. Notably, species with multiple uses, including *S. birrea*, *F. sur*, and *T. emetica*, were the most utilized. In addition, the commercial value of Marula, as indicated in various studies, underscores its potential for economic contributions. In addition, these species should be prioritized for urban greening, restoration activities, and forestry initiatives because of their cultural and socio-economic importance.

Treepreneurs, recognized for their vast knowledge on indigenous trees, demonstrated a strong commitment to propagation efforts, emphasizing the preference for indigenous species over alien invasive plants. This strongly aligns with the broader recognition of the environmental and economic benefits associated with indigenous tree species. Additionally, the study emphasizes the potential for income generation and socioeconomic contributions through indigenous tree growing and selling, particularly in peri-urban areas. Furthermore, the study encourages the exploration of hidden community economies, such as urban foraging of indigenous species, to tap into the potential benefits of indigenous produce in urban areas or cities. Hence, the planting of indigenous tree species is recommended in various urban areas to promote ethnobotanical knowledge. Thus, education and awareness programs are also crucial for informing communities about the benefits of indigenous tree species, and these efforts, if implemented in schools and around local communities, can contribute significantly to the wellbeing and development of rural, peri-urban, and urban communities.

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Chapter Three

Field Establishment of Indigenous Tree Species for Forestry and Food Security Using *Trichoderma Asperellum* at Ntshongweni, Durban, KwaZulu-Natal

Abstract

Indigenous tree species are recognized for their diverse benefits, including the value of their fibre and food products for rural communities. This study focused on the field establishment of five indigenous tree species from seedlings of *Trichilia emetica*, *Harpephyllum caffrum*, *Sclerocarya birrea*, *Ficus sur* and *Canthium inerme*. It also investigated the impact of a plant growth-promoting fungus, *Trichoderma asperellum*, on the survival and growth of the seedlings. The research was conducted at the Ntshongweni Nursery, Durban, KwaZulu-Natal, South Africa. *H. caffrum* demonstrated the highest survival rate (100%) compared to the other tree species. The seedlings of *F. sur* grew the fastest (33.13 cm). The study also established a strong, positive correlation ($P < 0.000237$), between tree height and root collar diameter. The study provided valuable insights into the survival and growth of the five indigenous tree species. Further research may explore the potential benefits of *Trichoderma* treatments in different conditions or with other species.

Keywords: Indigenous tree species; Plant growth-promoting fungus; *Trichoderma*; Field growth establishment; Tree survival; Tree height; RCD; Positive correlation; growth improvements.

3.1 Introduction

Global food security is a major challenge for the future, in light of the ongoing population growth, dietary changes, and climate change (Leisner, 2020). A change in climate means we must adapt our way of life and how we may live. Climate change has an impact on global food security and livelihoods (Connolly-Boutin and Smit, 2016), agriculture, forestry, and forest resources, access to water, and other activities related to agriculture that may alter the food systems and food production (Masipa, 2017; Kamara *et al.*, 2019; Ofori *et al.*, 2021) stated that smallholder food production is usually constrained by the lack of available resources, limited access to land, technology, and capital investment. As a result of climate change, it is likely that food derived from forests and tree-based ecosystems will continue to play a crucial role in household strategies to eradicate hunger and create nutritionally balanced diets (Mansourian *et al.*, 2015).

Indigenous trees offer a variety of benefits to people and the environment. They are used as a source of food and nutritional security in most developing countries (Bvenura and Sivakumar, 2017). Fruit from indigenous trees may be rich in essential minerals, vitamins, proteins, and phytochemicals (Omotayo and Aremu, 2020). Indigenous tree species play a vital role in maintaining the ecological balance and diversity of a region. They support wildlife habitats, protect soil from erosion, regulate the water cycle, and are essential in carbon sequestration, serving as a carbon sink to help mitigate the effects of climate change (Akinola *et al*., 2020). Additionally, compared to exotic species, indigenous tree species are adapted to the local climate and soil conditions, making them better suited for survival and growth in their natural environments (Chazdon and Guariguata, 2016). As much as they are important for the environment, they are also valuable to local communities in terms of their cultural, economic, and medicinal value. This is because many indigenous species are utilized as sources of traditional medicine, and they offer significant health benefits to rural communities. They may also provide important resources for livelihood survival such as fruit, timber, and fuelwood (Sardeshpande and Shackleton, 2019, 2020). In Northern Australia, approximately a total of 12.9 million ha of indigenous forests in the area have been determined to have appropriate potential for commercial wood production (Meadows *et al*., 2020). The region also has indigenous plantation forests that support small socioeconomic forestry and forest product sector (Meadows *et al*., 2020), and all these enterprises are mostly focused on benefitting indigenous communities in the area as well as the development of northern Australia (Meadows *et al*., 2020). Hence, it is important to preserve indigenous tree species to maintain the biodiversity of natural forests and to sustain natural environments, as well as the benefits and resources that they provide to local communities.

The establishment and survival of indigenous tree species play a crucial role in maintaining biodiversity and supporting local livelihoods in forested areas. The use of beneficial microorganisms and soil-borne fungi, such as *Trichoderma*, has shown promise in improving the growth, survival, and yield of crops in agriculture and forestry (Woo *et al*., 2014; Kashyap *et al*., 2017; Abdullah *et al*., 2021). *Trichoderma* is a genus of soil-borne fungi that has been found to have positive impacts on plant development and survival. Some strains of *Trichoderma* species enhance plant growth development, improving plant health and resilience to abiotic stress (Kashyap *et al*., 2017), as well as induce resistance to disease and pests (Pozo *et al*., 2021), and act as soil amendments to improve nutrient uptake ability (Woo *et al*., 2014). Studies of the effect of *Trichoderma* species on growth have been reported in rice plants

(Debnath *et al*., 2020), and many vegetable crops including bell pepper and tomato (dos Santos Pereira *et al*., 2020), as well as in olive trees (Bizos *et al*., 2020). The aim of this study was to evaluate the impact of a commercial strain of *Trichoderma* on the growth and survival of five selected indigenous tree species in a field establishment trial i.e., *Trichilia emetica*, *Harpephyllum caffrum*, *Sclerocarya birrea*, *Ficus sur* and *Canthium inerme*. These five indigenous species were chosen, based on social surveys that identified these species as useful within the communities around the trial site (Chapter Two).

3.2 Materials and Methods

3.2.1 Experimental Site

The field study was conducted at Ntshongweni Nursery, located at 29° 51’25”S 30° 40’19.5”E) Ezakhiweni, Durban, KwaZulu-Natal, South Africa. The nursery is situated 44 km west of Durban Central. The study was conducted from the 28th of March 2022 to the 6th of February 2023. Soil samples from the field were collected and analyzed for physical and chemical properties (Table 3.1**)**. All analyzed soil samples revealed their physical properties as loamy sandy soil in terms of texture.

Table 3.1: Chemical properties of soil samples taken at Ntshongweni nursery.

Soil Sample No.	pH (KCL)	pH (H_2O)	Ex. Acid	Ca (cmol/kg)	K (cmol/kg)	Mg (cmol/kg)	Na (cmol/kg)	S-value	P (mg/kg)	C (%)	N (%)	S (%)
1	6.23	6.23	1.08	0.97	0.17	0.49	0.03	1.65	8.82	0.316	0.027	0.0019
2	4.48	5.63	1.15	0.77	0.07	0.35	0.01	1.20	12.59	0.408	0.017	0.0076
3	4.35	5.49	0.20	0.66	0.07	0.36	0.02	1.11	2.36	0.414	0.016	0.00
4	7.43	6.78	0.07	3.46	0.14	0.50	0.01	4.11	21.11	0.524	0.037	0.00

3.2.2 Trial and Experimental Design

A factorial trial of the effect of *T. asperelluum* on five indigenous tree species (*Trichilia emetica* Vahl, *Harpephyllum caffrum* Bernh. ex C.Krauss, *Sclerocarya birrea* (A.Rich.)

Hochst, *Ficus sur* Forssk and *Canthium inerme* (L.f.) Kuntze was conducted. The trial was replicated three times with four plants per plot for each treatment. A second factor was the treatment levels i.e., Treatment with *Trichoderma* (Treated) and Treatment without *Trichoderma* (Untreated). The trees were planted in a Randomized Complete Blocks Design. Seedlings of the selected species were used to establish the trial. Their ages varied with each species. These were sourced from the Institute of Commercial Forestry Research (ICFR) and were initially grown in a shade house at the ICFR before they were transported to the field for planting. A commercial biological control agent of *Trichoderma asperellum* (EcoT - Andermatt PHP - Crop Protection and Crop Growth Enhancement (Andermatt-php.co.za)) was provided by the manufacturer. The sample was stored in a refrigerator at 4°C.

3.2.3 Planting of seedlings and *Trichoderma* drench application

The plants were transplanted into the field on the 28th of March 2022 in an area of 20 x 29m, in pits 20 x 20cm wide, and 30cm deep, with a spacing of 1.5m x 1.5m between trees. After planting the trees were irrigated with 5L of water. A drench suspension of Eco-T (1g/4L creating a suspension with 1×10^9 conidia/ml) was prepared in a 60 L drum. An amount of 1 L of drench was applied directly onto the soil and root system of each tree that requires *Trichoderma* application. This treatment was re-applied after 3 months. The trees were irrigated with 1L per tree approximately every five days, depending on the season and rainfall frequency.

3.2.4 Data Collection

Tree height (H), root collar diameter (rcd), tree survival, and general tree appearance were used to evaluate for tree performance and differential response to the growth-promoting fungus treatment. Tree height and RCD was measured first when the trees were planted, on Day Zero, and subsequent measurements were taken monthly. The survival percentage of trees was determined by counting of living and dead trees. Tree height (H) was measured from the stem baseline to the apical shoot (the highest point of the tree). Root collar diameter (RCD) was measured 2cm from the base of the stem, using a measuring tape (cm) and an electronic digital caliper (mm), respectively, to evaluate the growth and performance of the trees. The overall appearance of the trees in each plot was observed to monitor and evaluate for tree health. The number of living trees in each plot at the end of the experiment served as the survival metric. The data collected was used to compare the survival and growth of indigenous species over time, with and without *Trichoderma* treatment under field conditions.

3.2.5 Statistical Analysis

Statistical analysis of all data was performed using GenStat 23rd edition. The data was subjected to statistical analysis of variance, and to determine differences between treatments, Fisher's Unprotected Least Significant Difference Test was used ($P = 0.05$). The growth of different indigenous tree species under field conditions was assessed and quantified using the Area Under Growth Curve (AUGC) metric, which was adapted from the Area Under the Disease Progress Curve (AUDPC) (Madden *et al.*, 2007). The trapezoidal method was used to calculate the AUGC by using the time variable of days and estimating the average growth between each pair of adjacent time points. Madden *et al.* (2007) explained that "the sample time points in a sequence $\{t_i\}$, where the time interval between two-time points may be consistent or may vary", and there are "associated measures of the growth level $\{y_i\}$." They defined "$y(0) = y_0$ as the initial growth at $t = 0$ (i.e., the first day measurements in our study). $A(t_k)$, the AUGC at $t = t_k$, is the total growth until $t = t_k$, given by $A_K = \sum_{i-1}^{N_{t-1}} \frac{(y_i + y_{i+1})}{2} (t_{i+1} - t_i)$.

3.3 Results

3.3.1 The effect of growth-promoting fungal treatment on indigenous tree survival under field conditions

The overall tree survival at 10 months post-planting was 94.2%. *Trichoderma* inoculation as a drench solution had no significant effect ($p > 0.05$) on tree survival. *H. caffrum* (100%), had the highest survival rate even after encountering livestock grazing. *F. sur* and *S. birrea* had a similar survival percentage after both treatments, 83.3 and 91.7% in untreated and treated plots, respectively (Table 3.3). One of the challenges of the trial was that cattle from the neighboring community browsed on some trees. Some trees never recovered from the browsing event. Others managed to produce new shoots.

Table 3.2: The survival percentage of five indigenous tree species after being treated with a growth-promoting fungal treatment under field conditions after 10 months (N = 24 trees, i.e., 12 per species)

Species	**Untreated**		**Survival rate (%)**	**Treated**		**Survival rate (%)**
	Grazed	Survived		Grazed	Survived	
H. caffrum	12	12	100	10	12	100
C. inerme	12	11	91.67	12	12	100
T. emetica	10	12	100	12	10	83.33
S. birrea	12	10	83.3	12	11	91.7
F. sur	12	10	83.3	12	11	91.7
P -value	**< 0.05**					

3.3.2 The effect of a growth-promoting fungal treatment on the growth of height and RCD of five indigenous tree species under field conditions

Statistically, there were significant differences between species in the parameter of increased height ($p < 0.001$) and rcd ($p = 0.024$) (Table 3.4). The inoculation of *Trichoderma* treatment on indigenous tree species had no effect on the growth promotion of the trees in terms of height ($p = 0.391$) and root collar diameter ($p = 0.933$). In addition, analysis of variance showed that there was no special interaction between *Trichoderma* treatment and one or more tree species in height ($p = 0.193$) and rcd ($p = 0.988$). According to these results, no treatment was observed to perform better than the other (Figure 3.3 and 3.4). However, changes in growth over the period of investigation were observed (Appendix 3, Figure 3.1 and3.2).

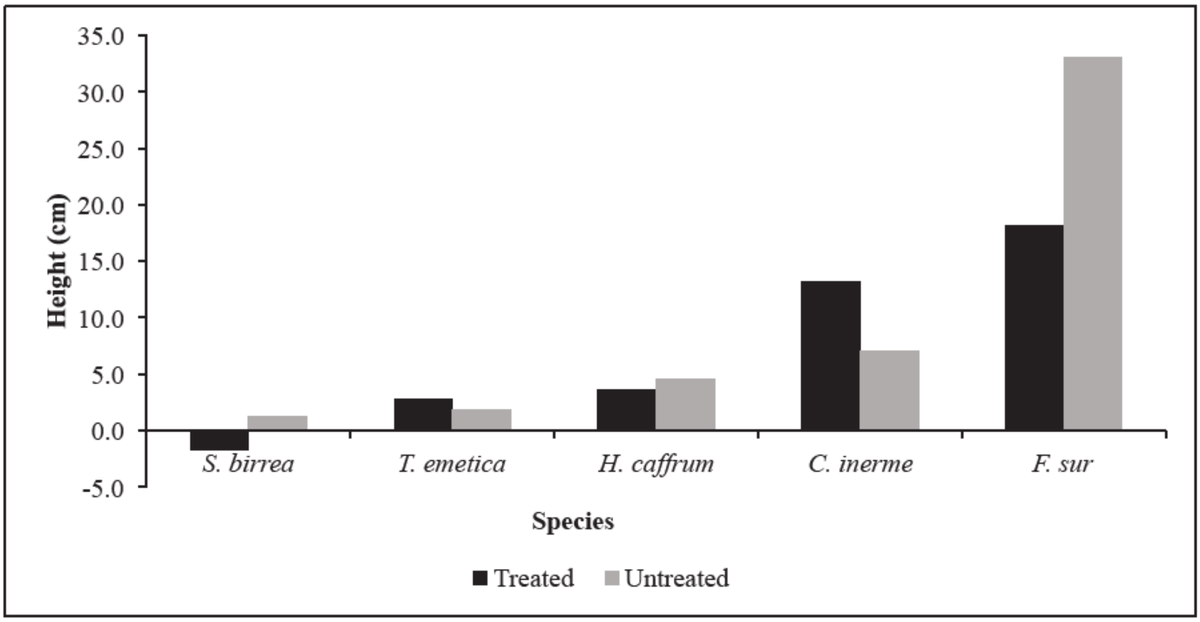

Figure 3.1: Change in the growth of indigenous tree species in average height after 10 months under field conditions at Ntshongweni, Durban (n=24).

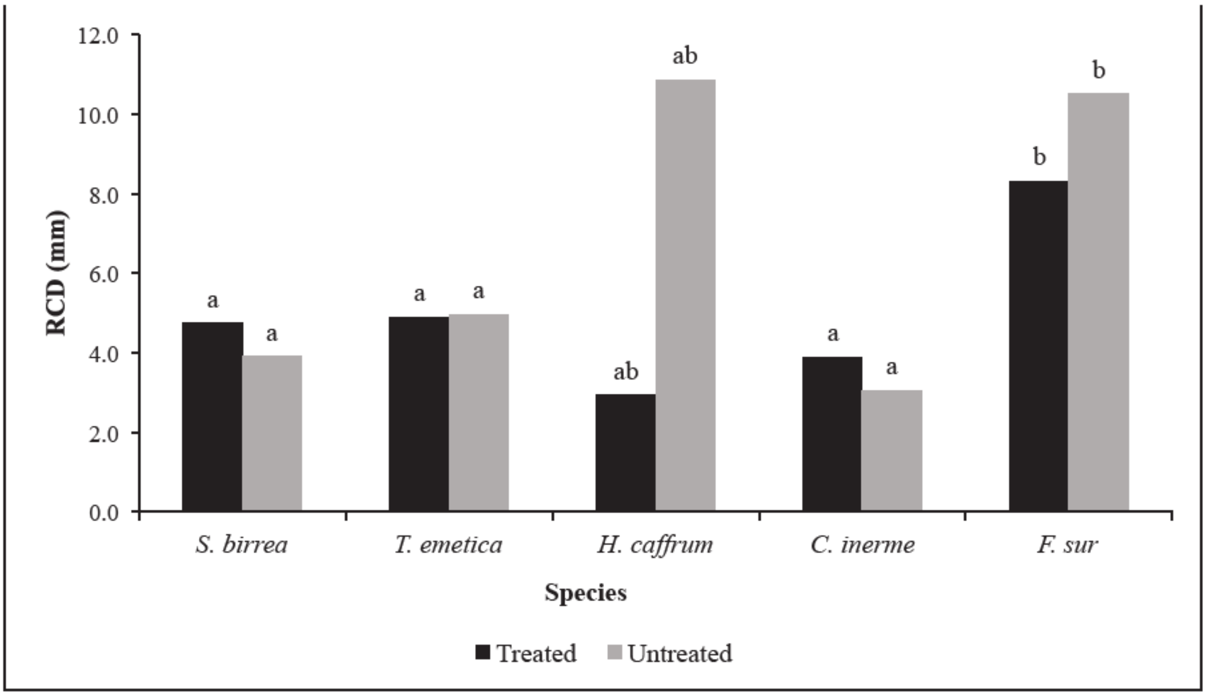

Figure 3.2: Change in the growth of indigenous tree species in average root collar diameter (RCD) after 10 months under field conditions at Ntshongweni, Durban (n=24).

Table 3.3: ANOVA obtained from the growth of indigenous tree species in height and RCD, under field conditions over a period of 10 months.

Variate Height	**S.S.**	**M.S.**	**V.R.**	**F Pr.**
Tree Species	2875.46	718.86	9.72	<.001
Trichoderma	56.96	56.96	0.77	0.391
Tree species x *Trichoderma*	498.62	124.66	1.69	0.193
S.E	8.60			
CV (%)	103.0			
Variate RCD				
Tree Species	608.93	152.23	3.56	0.024
Trichoderma	0.31	0.31	0.01	0.933
Tree species x *Trichoderm*a	13.46	3.37	0.08	0.988
S.E	6.54			
CV (%)	89.5			

F. sur and *C. inerme* showed the greatest change in mean height of 33.13 cm and 13.18 mm, respectively. Regarding root collar diameter (rcd), the greatest change was observed in *H. caffrum* (10.87 mm) and *F. sur* (10.51mm), with the least being *C. inerme* (3.06 mm) (Figure 3.3).

3.3.3 Growth response of indigenous tree species to the application of a growth promoting fungus as quantified by Area Under the Growth Curve (AUGC).

The growth of the five indigenous tree species treated with *Trichoderma* under field conditions was assessed and quantified using the AUGC metric. AUGC as a measure of overall growth was found to be insignificant between all species investigated for the applied *Trichoderma* treatment ($p > 0.05$) (Table 3.4). As shown in Table 3.4, no species exhibited a significant increase between treated and untreated, suggesting that the application of the *Trichoderma* treatment had no impact on growth in either height or RCD. Between the five species, *T. emetica* followed by *H. caffrum,* exhibited the highest overall AUGC in terms of height, and *H. caffrum*, followed by *F. sur* exhibited the highest AUGC in terms of RCD (Appendix 3, Table 3.1). This analysis corresponds with results from the above sub-section where the mentioned tree species compared to others, displayed the highest changes in growth of both height and diameter, even though statistical analysis showed no significant increase in their respective growth.

Lastly, the coefficient of variation (CV) values of 27.8% and 20.5% in terms of height and RCD AUGC, respectively, display moderate levels of variability, which is good in terms for a field trial.

Table 3.4: ANOVA of AUGC for indigenous tree species under field conditions over a period of 10 months.

Variate Height	**S.S.**	**M.S.**	**V.R.**	**F PR.**
Tree Species	39571880	9892970	1.03	0.418
Trichoderma	22679357	22679357	2.35	0.141
Tree species x *Trichoderma*	25645455	6411364	0.66	0.624
S.E	3105.40			
CV (%)	27.8			
Variate RCD				
Tree Species	19773210	4943303	12.65	<.001
Trichoderma	114145	114145	0.29	0.595
Tree species x *Trichoderma*	183745	45936	0.12	0.975
S.E	625.02			
CV (%)	20.5			

3.3.4 The correlation between Height and RCD for five indigenous tree species grown under field conditions.

There was a significant positive correlation between tree height and RCD of the investigated indigenous tree species. Figure 3.4 illustrates a positive relationship where an increase in height is matched by an increase in RCD, and this is supported by the linear regression coefficient of determination (R^2) of 0.39, showing a moderate correlation between the two parameters. Additionally, this relationship is further supported by the value of $P < 0.000237$, suggesting a highly statistically significant correlation between height and RCD.

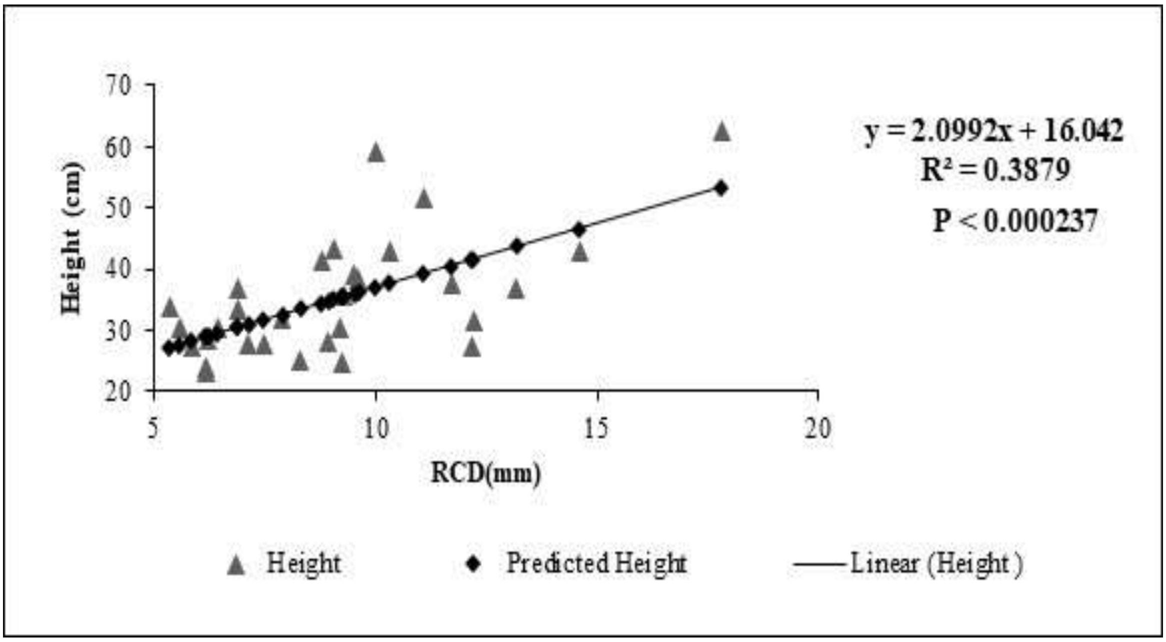

Figure 3.3: Linear Regression model between Height and RCD over a period of 10 months under field conditions.

3.4 Discussion

Numerous studies have documented the benefits of applying *Trichoderma* for plant growth and increased production. According to Sánchez-Montesinos *et al.* (2020), the application of *Trichoderma* species, to both soil and seeds enables the fungus to multiply in conjunction with the developing root system. Additionally, its ability to invade and colonize plant roots directly enhances seed vigor and germination as well as promotes seedling growth. Typical signs of growth promotion are increased biomass in the roots and shoots but also, changes in plant morphology and development have been reported. *Trichoderma* may be applied directly to the soil as well as in granular form and as a drench at the nursery stage (Ghazanfar *et al.*, 2018).

However, in this study, the inoculation of *Trichoderma* treatment on indigenous trees directly onto the root and soil systems as a drench solution under field conditions caused no significant effect on either growth or survival of seedlings (Tables 3.3 and 3.4). These results are not in agreement with various studies that have investigated the effect of *Trichoderma* on growth promotion (Griebeler *et al.*, 2021) of the role of *Trichoderma* in growth promotion can be influenced by several limiting factors such as crop type, growing conditions (availability of nutrients, soil pH, or temperature), inoculum rate, and formulation type (Griebeler *et al.*, 2021; Stewart and Hill, 2014). Furthermore, a study by Sánchez-Montesinos *et al.* (2020) suggested that such growth-promoting fungi like *Trichoderma* should be applied at the plant nursery stage for horticultural, ornamental, and forest plants. This allows for the early colonization of the roots by *Trichoderma*, before transplanting the seedlings in the field.

Regarding the promotion of growth of indigenous tree species by beneficial microorganisms or growth-promoting fungi, the application of *Trichoderma* was not significant for any of the species (Tables 3.4 and 3.5) using height, RCD and AUGC as the parameter for growth. . Although, various studies conducted on species native to their countries, especially in South America and Asia, demonstrated that the use of *Trichoderma* spp. provide an option to increase the growth rates of tree forest species in field plantations (Griebeler *et al*., 2021). A study by Soldan *et al*. (2018) reported a significant improvement in the growth of *Eugenia pyriformis* at 540 days after planting in a field using a commercial product based on *Trichoderma* spp. However, the importance of identifying appropriate isolates is emphasized, as there are specificities for each species and location of application (Griebeler *et al*., 2021).

Among the species investigated, *H. caffrum* had the highest survival rate of 100% (both treatments), followed by *C. inerme* with 91.67% (untreated) and 100% (treated, Table 3.3). This indicates that these species are suitable for a community forestry setting. According to Burring (2004), while competing for space under forest conditions, *C. inerme* is more likely to grow into a tall tree, and under conducive conditions with adequate space and good light intensity, it can grow taller than 5m. However, in a study by Obiri *et al*. (2002), this species had a low survival rate due to its inability to coppice and resprout after harvesting or browsing injury. The species with the largest RCD was *H. caffrum.* (dos Santos *et al*., 2019) asserted that an increase in collar diameter reflected an increasing survival capability of seedlings in the field.

The lower survival rates of *S. birrea* and *F. sur* (83.3% untreated and 91.67 treated, Table 3.3) may be attributed to the impact of grazing that affected the growth and survival of these species. Additionally, during field inspections, termites were observed to be attacking these species' roots. *S. birrea* is highly vulnerable because it is deciduous (shed leaves in winter) and was severely affected by grazing, thus some trees could not recover. The growth of some *S. birrea* trees began to improve at the end of the winter season. Nyoka *et al*. (2015) also reported similar challenges regarding livestock grazing on trees in their trial.

F. sur exhibited the overall highest change in mean height, RCD, and AUGC values, which reflect its characteristics as a fast-growing timber and fruit-producing tree (Essien *et al*., 2012).

In the present study, the growth patterns of indigenous tree species reveal a positive correlation between tree height and RCD over a period of 10 months. Statistical analysis yielded a very significant p-value $P < 0.000237$, and $R2 = 0.39$ (Figure 3.4). This demonstrates that increases in tree height are correlated with increases in RCD. In similar studies by Dlamini (2010), and Nyoka *et al*. (2015) a similar positive correlation between height and diameter in an indigenous tree species, *S. birrea*, was observed. In the study by Dlamini (2010), the correlation was significant but weak over a period of 8 months ($P = 0.02$, $R2 = 0.18$).

3.5 Conclusions

Based on the findings of our study, it is recommended that *Trichoderma* is trialled as a plant growth promoter at the seedling stage to produce more robust saplings. In the local context, this may help restoration programmes such as the Treepreneurs, as well as indigenous nurseries, to propagate and plant indigenous saplings more effectively (Tsvuura *et al*. 2023). Additionally, when planting indigenous saplings in spaces of intensive human use, due consideration should be given to plant phenology. Specifically, if plants are exposed to grazing and extraction by humans, slightly mature plants are more likely to survive. Further, field transplantation should be timed to the seasonal cycles of the species to afford it minimal damage from exposure during senescence periods, as in the case of *S. birrea*.

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Chapter Four

Pot Trial of Indigenous Trees vs Commercial Exotic Species Using Degraded Soils with Incorporation of *Trichoderma Asperellum*, Under Greenhouse Conditions

Abstract

Indigenous tree species have adapted and evolved to thrive under local conditions, considering the climate, soil, and environmental conditions as well as other ecological aspects. This study focused on growing indigenous tree species i.e., *Trichilia emetica*, *Harpephyllum caffrum*, *Sclerocarya birrea*, *Ficus sur* and *Canthium inerme*, under greenhouse conditions using anthropogenic soil from degraded lands and comparing their growth forms to commercial exotic species *Eucalyptus grandis*. It also investigated the use of plant growth-promoting fungus, specifically *Trichoderma asperellum*, on the survival and growth of the indigenous tree seedlings compared to a control species *Eucalyptus grandis* which was not treated. The research was conducted under a greenhouse in pots at Controlled Environmental Research Unit (CERU), at the University of KwaZulu-Natal (UKZN). All indigenous tree species exhibited the highest survival percentage of 100% except for *Sclerocarya birrea* with a survival percentage between 67 and 92% in both treated and untreated samples, respectively. The seedling of *Ficus sur* grew faster than the rest with 48.8 cm in height but not as compared to the control species accounting for 99.34 cm. A weak positive correlation between height and root collar diameter was established in this study for indigenous tree species with $p = 0.012$, $R^2 = 18\%$ compared to a strong correlation of $R^2 = 78\%$ for the control species *E. grandis*. The incorporation of *Trichoderma* treatment in growth showed no significant effect on tree height and root collar diameter $P = 0.838$ and $P = 0.556$), respectively. Statistically, the AUGC as a measure of growth was not significant in both height and rcd accounting for $P = 0.635$ and 0.942, respectively. However, only *H. caffrum* and *F. sur* exhibited the highest AUGC for height and rcd. This study highlights the potential of selecting indigenous tree species and emphasizes the need for further development of these species for forestry and restoration initiatives.

Keywords: Indigenous tree species; greenhouse conditions; anthropogenic soil; Trichoderma *asperellum*; survival percentage; height; root collar diameter; AUGC; *Harpephyllum caffrum*; *Ficus sur*; *Eucalyptus grandis*; forestry; restoration initiatives.

4.1 Introduction

Over the years, it has become obvious that climate change is an inevitable phenomenon due to its anticipated detrimental effects such as warming and changes in rainfall patterns (Thompson *et al*., 2010). Other existing effects of climate change include food insecurity prevalence, as a result of land and soil degradation. Soil degradation is the loss of soil fertility and characteristics caused by various factors such as negligent usage of agricultural, pastural and industrial land, as well as deforestation, urbanization, and climate changes (Alam, 2014). It is a catastrophic global ecological problem facing mankind, which does not only weaken the ability to produce, but has environmental and economic impacts (Thompson *et al*., 2010; Alam, 2014). This can lead to reduced soil productivity, reduced crop yield, increased soil erosion, and biodiversity loss, as well as overall ecosystem imbalances, reduced water quality (Hossain *et al*., 2020).

Soil degradation can also have huge impacts on plant growth by reducing nutrient and water availability and modifying soil structure and composition (Coban *et al*., 2022). This may cause difficulties for roots penetration in the soil and for them to absorb the required nutrients and water, which is essential for growth. To restore degraded land and soil, and enhance plant growth, researchers and land managers are still investigating a range of strategies, such as the use of indigenous tree species and biological control agents (Di Sacco *et al*., 2021; Coban *et al*., 2022). Indigenous trees are perceived as a more environmentally friendly and a more sustainable alternative to exotic monocultures, which are often associated with negative impacts on local ecosystems (Belluau *et al*., 2021; Di Sacco *et al*., 2021). Typical impacts include the loss of biodiversity, increase in invasive species, disruption of water cycles, and a decline in carbon stocks and soil organic carbon (Veldman *et al*., 2019; Di Sacco *et al*., 2021;).

On the other hand, indigenous tree species have adapted and evolved to thrive under local conditions, considering the climate, soil, and environmental conditions as well as other ecological aspects (Chazdon and Guariguata, 2016)). So, planting of indigenous tree species can offer ecological benefits such as nutrient cycling, enhancement of soil organic matter, soil structure improvement, reduction in soil erosion, soil stabilization as well as water retention (Basey *et al*., 2015; Mensah, 2015; Almas and Conway, 2016). Hence, their utilization in soil and land restoration can help achieve a more balanced and sustainable ecosystem through the provision of important ecological services (Basey *et al*., 2015; Kumar *et al*., 2023).

Soil microorganisms play an important role in agriculture and forestry, they are not only perceived as indicators of soil health since they can promote health and nutrient availability and cycling (Adedeji *et al*., 2020), but can also facilitate soil restoration (Lu *et al*., 2023). Such microbes can improve growth of plants and improve soil quality through a mutualistic interaction in the rhizosphere, as well as play a role in plant pathogen suppression (Adedeji *et al*., 2020; Kumar *et al*., 2023).

For this study, *Trichoderma* spp is used as a type of fungi that is known for its ability to improve soil health and promote plant growth (Bizos *et al*., 2020). By incorporating *Trichoderma* spp into degraded soil, it is possible to promote healthy plant growth and restore the natural balance of the ecosystem (Kumar *et al*., 2023). In this study, the aim was to evaluate the impact of a commercial strain of *Trichoderma asperellum* on the growth and survival of five selected indigenous tree species under greenhouse conditions. This was done by comparing the growth of indigenous trees with commercial exotic species in degraded soils that have been amended with the biological control agent *Trichoderma* spp, as well as to determine which type of tree is better suited for reforestation efforts in degraded soil conditions.

4.2 Materials and Methods

4.2.1 Experimental Site

The study was conducted at the controlled Environmental Research Unit (CERU), Agronomy tunnel, located at 29°37’36.9”S 30°24’13.1”E, at the University of KwaZulu-Natal (UKZN). The experiment was conducted from the 1st of April 2022 to December 2022. during the conduct of this study, the average temperature was 25 °C min and 30 °C max.

4.2.2 Soil Collection and Sampling

Anthropogenic soils from degraded lands were used for the purpose of this study. Degraded lands are a composition of soils that remain after the action of land degradation through soil erosion and improper agricultural management which thus results in loss of organic matter and a decline in soil fertility (Obalum *et al*., 2017). Such soils were identified at Buffelsdraai Landfill Site (29° 37’54.3” S, 30° 58’43.4” E) where previously it was a sugarcane site. Nine 80 kg sacks were filled with the soil and then later mixed to homogenize the soil.

Homogenized soil samples were collected and analysed for chemical and physical properties characteristics. The analysed soil samples revealed their physical properties as clay loamy soil in terms of texture, with a moisture factor of 1.

Table 4.1: Chemical properties of soil samples taken from the Buffelsdraai landfill site in Durban

Sample No.	pH (KCL)	pH (H_2O)	Ex. Acid	Ca (cmol/kg)	K (cmol/kg)	Mg (cmol/kg)	Na (cmol/kg)	S-value	P (mg/kg)	C (%)	N (%)	S (%)
1	4,96	5,69	0,05	2,78	0,36	4,23	0,29	7,65	21,14	1.286	0.088	0.0154
2	4,83	5,6	0,1	2,62	0,36	4,05	0,27	7,3	4,46	1.302	0.105	0.0243
3	4,71	5,41	0,13	2,72	0,7	4,14	0,27	7,83	44,15	1.220	0.091	0.0291

4.2.3 Trial and Experimental Design

The experiment was carried out in a completely randomized design, with 5 different indigenous species (*Trichilia emetica* Vahl, *Harpephyllum caffrum* Bernh. ex C.Krauss, *Sclerocarya birrea* (A.Rich.) Hochst, *Ficus sur* Forssk and *Canthium inerme* (L.f.) Kuntze), 30 plots, 4 experimental units, 2 treatments (*Trichoderma* treated and untreated), with three replications per treatment and 10 control trees of *Eucalyptus grandis*. Each indigenous species had 24 trees, and in total 120 indigenous trees plus 10 exotic trees of *Eucalyptus grandis* were planted. Seedlings of the selected indigenous species were supplied by the Wildlands Trust from eThekwini and *Eucalyptus* seedling were provided by the ICFR Nursery, and all were stored in a shade house at ICFR Nursery before planting. A packet of commercially recognized biological control agents *Trichoderma asperellum* (*Eco-T*) was provided and stored in a refrigerator at 4 ºC. As per application rate of 1g/1L, 60 g of *Eco-T* was weighed and stored in a refrigerator in glass tubes at 4 ºC.

4.2.4 Seedling transplanting and treatment application

Seedling transplanting was carried out on the 1st of April 2022, on 25cm pots filled with homogenized soil. After planting the seedlings were irrigated with 1L of water for hydration. Drench solution of *Eco-T* and water was prepared as per application rate in a 20 L bucket. An amount of 1 L of drench was applied directly onto the soil and root system for trees that require *Trichoderma* application, as per trial map design, and this treatment was applied one more time after 3 months. After planting, the trees were then irrigated after every 3 or 4 days. In addition, during the experiment, periodic monitoring of trial was carried out survival and growth evaluation as well as manual weeding around seedlings in pots.

4.2.5 Data Collection and Analysis

Tree height (H), root collar diameter (rcd), survival percentage, and general tree appearance were used to evaluate for tree performance and differential response to the growth-promoting fungus treatment against the commercial species *Eucalyptus grandis* used as a control.

Tree height and RCD was measured first when the trees were planted, on Day Zero, and subsequent measurements were taken monthly. Tree height (H) was measured from the stem baseline to the apical shoot (the highest point of the tree). Root collar diameter (RCD) was measured 2cm from the base of the stem, using a measuring tape (cm) and an electronic digital calliper (mm), respectively, to evaluate the growth and performance of the trees. Tree survival percentage was calculated by counting all surviving trees at the end of the investigation period. The overall appearance of the trees in each plot was observed to monitor and evaluate tree health. The data collected was used to compare the growth of the five indigenous species with that of exotic *Eucalyptus grandis* control. The data collected may be used to extrapolate the expected growth trajectory of the surviving seedlings.

4.2.6 Statistical Analysis

Statistical analysis of all data was performed using GenStat 23rd edition. The data was subjected to statistical analysis of variance, and to determine differences between treatments, Fisher's Unprotected Least Significant Difference Test was used (P = 0.05).

The growth of different indigenous tree species under field conditions was assessed and quantified using the Area Under Growth Curve (AUGC) metric, which was adapted from the Area Under the Disease Progress Curve (AUDPC) (Madden *et al.*, 2007). The trapezoidal method was used to calculate the AUGC by using the time variable of days and estimating the average growth between each pair of adjacent time points. Madden *et al.* (2007) explained that "the sample time points in a sequence $\{t_i\}$, where the time interval between two-time points may be consistent or may vary", and there are "associated measures of the growth level $\{y_i\}$." They defined "$y(0) = y_0$ as the initial growth at $t = 0$ (i.e., the first-day measurements in our study). $A(t_k)$, the AUGC at $t = t_k$, is the total growth until $t = t_k$, given by

$$A_K = \sum_{i-1}^{N_{t-1}} \frac{(y_i + y_{i+1})}{2} (t_{i+1} - t_i)$$

4.3 Results

4.3.1 The Effect of *T. asperellum* Treatment on Indigenous Tree Survival Under Greenhouse Conditions against a Commercial Exotic Species *Eucalyptus Grandis*

Tree survival at the end of the investigation period was generally high ranging from 67 to 100% for the five indigenous tree species used in this study. *S. birrea* tree seedlings treated with the growth-promoting fungus had the lowest survival percentage of 67% and untreated seedlings accounting for 92% (Table 4.2). However, the treatment showed no significant effect on survival of the indigenous tree species under greenhouse conditions.

Table 4.2: The survival percentage of five indigenous tree species after being treated with a growth-promoting fungal treatment under field conditions against commercial exotic species after 9 months (N = 24 trees, i.e., 12 per species)

Species	**Untreated**		**Survival %**	**Treated**		**Survival %**
	Planted	**Survived**		**Planted**	**Survived**	
H. caffrum	12	12	100	12	12	100
T. emetica	12	12	100	12	12	100
F. sur	12	12	100	12	12	100
C. inerme	12	12	100	12	12	100
S. birrea	12	11	92	12	8	67
E. grandis (control)	10	10	100	*E. grandis* (control) was not treated with *T. asperellum*		

4.3.2 The Effect of *T. asperellum* Treatment on The Growth of Height and Root Collar Diameter of Indigenous Tree Species Vs Exotic Species *E. grandis* Under Greenhouse Conditions

The effect of growth-promoting treatment of *Trichoderma* on height and rcd on indigenous tree species is presented in Table 4.3 and 4.4. Statistically, there were significant differences between species in the parameter of increased height and rcd ($p < 0.001$) (Table 4.3 and 4.4). Among all species evaluated, the highest change in average height and rcd was observed in *F. sur* with *T. asperellum* accounting for 48.8 cm and 9.84 mm over 9 months, respectively. Only *S. birrea* and *C. inerme* had the lowest average change in the growth of height and rcd. However, the average change in growth in height and rcd of *F. sur* was significantly lower than that of the control species *E. grandis* which accounted for 109.16 cm and 12,20 mm in height and rcd, respectively. In addition, no treatments had a significant effect on the growth of indigenous trees compared to exotic *Eucalyptus grandis* which was not treated accounting for $p < 0.001$ (Table 4.3).

Lastly, the coefficient of variation (CV) for a greenhouse pot trial after 9 months is extremely higher than the accepted value of 25%, accounting 53.3 and 32.7 % for height and RCD variate, respectively, displaying high levels of variability.

Table 4.3: Mean height of indigenous tree species treated with *T. asperellum* under greenhouse conditions for over 9 months (240 Days After Planting).

Treatments	**0DAP**	**30DAP**	**60DAP**	**90DAP**	**120DAP**	**150DAP**	**180DAP**	**210DAP**	**240DAP**
Control	29.67bc	31.92bcd	40.79cd	43.25bcd	51.75d	60.92d	98.83d	128.92c	138.83d
H. caffrum	41.84e	38.68bcd	45.92d	50.71d	50.42d	49.75cd	55.83c	61.25b	66.83bc
H. caffrum + *T. asperellum*	38.32cde	42.23d	41.50cd	47.33cd	45.17cd	40.92bc	44.33bc	46.08b	56.67bc
T. emetica	30.64bcd	30.83bc	33.75bc	34.50bc	33.08bc	33.17b	37.33bc	42.58b	47.17bc
T. emetica + *T. asperellum*	30.04bc	30.22b	30.83bc	34.08bc	33.42bc	31.50b	35.83bc	41.42ab	40.75ab
F. sur	26.98b	28.61b	28.42b	29.00b	29.17b	28.67b	33.75b	37.58ab	49.92bc
F. sur + *T. asperellum*	35.37bcde	35.01bcd	35.92bcd	36.00bcd	37.75bcd	28.67b	44.00bc	61.00b	83.42c
C. inerme	8.21a	8.13a	8.83a	8.45a	8.15a	8.47a	8.47a	9.19a	9.48a
C. inerme + *T. asperellum*	8.74a	8.84a	8.14a	7.29a	7.23a	7.48a	8.88a	9.19a	9.91a
S. birrea	39.74cde	38.79bcd	33.25bc	29.00b	27.46b	27.75b	28.67ab	31.08ab	32.00ab
S. birrea + *T. asperellum*	40.54de	41.04cd	40.58cd	39.42bcd	38.83bcd	37.42bc	40.42bc	42.92b	44.75ab
P value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
LSD	6.190	6.397	7.298	9.175	8.835	9.48	13.46	19.93	22.69
CV%	25.5	26.0	28.5	34.8	33.2	35.1	42.0	53.1	53.3

Table 4.4: Mean RCD of indigenous tree species treated with *T. asperellum* under greenhouse conditions over a period of 9 months (240 DAP)

Treatments	**0DAP**	**30DAP**	**60DAP**	**90DAP**	**120DAP**	**150DAP**	**180DAP**	**210DAP**	**240DAP**
Control	2.546a	2.952a	4.066a	4.927a	6.633ab	8.059b	9.51bc	12.84d	14.75cd
H. caffrum	15.440d	15.963d	17.204e	17.362d	17.628e	17.857e	19.02f	20.07f	20.66e
H. caffrum + *T. asperellum*	13.368c	13.992c	14.509d	14.526c	15.363d	15.600d	15.85e	17.39ef	18.45e
T. emetica	8.080b	8.288b	8.301c	7.907b	8.186bc	9.194bc	10.02cd	11.62bcd	11.70bc
T. emetica + *T. asperellum*	7.167b	7.797b	8.317c	7.932b	8.224bc	8.456b	9.20bc	11.20bcd	10.64b
F. sur	7.399b	7.402b	7.272bc	7.241b	7.531b	8.893bc	9.72bc	12.21cd	14.35cd
F. sur + *T. asperellum*	7.622b	7.758b	7.664bc	8.514b	9.607c	10.984c	12.21d	16.18e	17.46de
C. inerme	8.740b	8.837b	8.831c	8.454b	8.153bc	7.482b	8.47bc	9.19bc	9.49b
C. inerme + *T. asperellum*	8.206b	8.126b	8.831c	7.292b	7.228b	8.473b	8.88bc	9.19bc	9.92b
S. birrea	8.267b	7.535b	5.960b	5.123a	4.717a	4.914a	5.56a	5.90a	5.92a
S. birrea + *T. asperellum*	8.250b	8.452b	8.150c	7.371b	7.200b	7.605b	7.40ab	9.02b	9.21ab
P value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
LSD	1.981	1.764	1.891	2.038	2.062	2.169	2.427	3.105	3.427
CV%	28.4	24.7	26.1	28.7	27.9	27.5	28.5	31.3	32.7

4.3.3 Growth Response of Indigenous Tree Species to The Application of *T. asperellum* as Quantified by Area Under the Growth Curve (AUGC*)* for Over 9 Months

The AUGC metric was used to evaluate and assess for growth of the five indigenous tree species against the commercial exotic species *Eucalyptus grandis*. Statistically, the AUGC as a measure of growth was not significant in both height and rcd accounting for P = 0.635 and 0.942, respectively (Table 4.3). This suggests that the treatment of *Trichoderma* did not have any significant effect on the AUGC of the five indigenous tree species investigated in this study however, only *H. caffrum* and *F. sur* exhibits the highest AUGC for height and rcd even though AUGC height is still lower than that of the control (Appendix 4, Table 4.1).

Interestingly, the coefficient of variation (CV) of height AUGC displays good levels of variability even though CV for rcd is extremely high at 163.6% displaying very high levels of variability.

Table 4.3: ANOVA of AUGC for indigenous tree species in height and RCD, under greenhouse conditions over a period of investigation.

Variate Height AUGC-Control	**S.S.**	**M.S.**	**V.R.**	**F Pr.**	**LSD**
Trichoderma	0.376	0.376	0.23	0.635	0.465
Tree Species	296.405	74.101	45.67	<.001	0.735
Trichoderma vs Tree Species	14.298	3.575	2.20	0.105	1.040
SE	1.274				
CV (%)	22.7				
Variate RCD AUGC-Control					
Trichoderma	0.18	0.18	0.01	0.942	4.33
Tree Species	764.22	191.05	5.90	0.003	6.85
Trichoderma vs Tree Species	571.22	142.81	4.41	0.010	9.69
SE	5.69				
CV (%)	163.6				

4.3.4 The Correlation Between Height and RCD for Five Indigenous Tree Species Against Commercial Exotic Species *E. grandis* (Control) Grown Under Greenhouse Conditions.

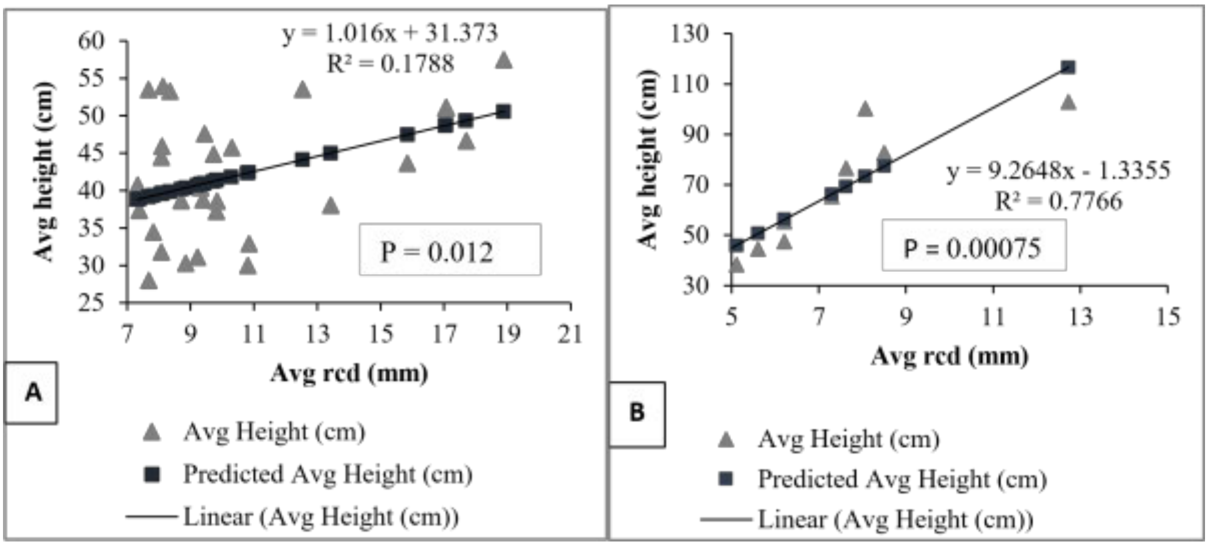

Figure 4.2: Linear Regression model between Height and RCD of indigenous tree species against E. grandis over 9 months under greenhouse conditions. (A= Indigenous tree species, B = *E. grandis*.)

There was a significant positive correlation between tree height and RCD of the investigated indigenous tree species. Figure 4.2 illustrates a positive relationship in the growth of indigenous tree species and the *Eucalyptus* spp. where an increase in height is matched by an increase in RCD. However, the linear regression coefficient of determination (R^2) for the indigenous tree species under investigation (R^2 = 18%) is very low when compared to that of the commercial exotic *E. grandis* (R^2 = 78) which is very high, showing a high correlation between the two parameters (height and rcd) in terms of growth.

4.4 Discussion

The findings from this greenhouse pot trial conducted on degraded soils from the Buffelsdraai landfill site underscore the initial selection of exotic species for commercial forestry in South Africa due to their rapid growth characteristics. In this study, there were significant difference in adding growth-promoting fungus to anthropogenic soils as an effort to enhance growth of indigenous tree species when compared to the commercial exotic species control *E. grandis*. However, extensive development of indigenous tree species is needed to explore the wide benefits indigenous species can offer in food, forestry, and ecology.

At the end of the trial, overall survival amongst the indigenous tree species used for this study was consistent with that of the control species. However, a single indigenous tree species *S. birrea* had a survival percentage of less than a hundred accounting for 67 and 92% of the trees amended with *Trichoderma* (treated) and without *Trichoderma* (untreated), respectively. This species' low survival percentage can be explained by transplant shock which most likely affected the seedling performance (Sonti *et al*., 2022). Additionally, the survival rate is considered an important metric in the success of restoring degraded lands for economic and environmental success (Preece *et al*., 2023). Similar patterns were observed in this study and studies by Preece *et al*. (2023) and Sonti *et al*. (2022) that indigenous tree species mortality caused by transplant shock in the first few months of the growing period affects the overall survival rate at the end of the growing period. They further add that to reduce transplant shock and mortality at the first stages of growth, adequate watering is required (Sonti *et al*., 2022).

Two growth parameters were measured in this study i.e., height and rcd and these parameters are considered important factors for commercial forestry (da Costa Alpoim, 2021; Bahru *et al*., 2023;). The five indigenous tree species demonstrated the ability to grow and survive in anthropogenic soils sourced from a dumping site, amended with a growth-promoting fungal treatment. In this study, only *F. sur* exhibited the highest growth in height and rcd with no statistically significant effect by the treatment ($p < 0.001$) but as expected, these parameters were considerably lower than that of the control (*E. grandis*) (Table 4.3; 4.4). This indigenous tree species *F. sur* exhibits similar growth patterns in this study and in the study conducted under field conditions (Chapter 3) indicating great potential for forestry use and is also considered fast fast-growing for an indigenous species (Essien *et al*., 2012; Negash, 2021).

The growth patterns of indigenous tree species can further be explained by the AUGC metric which was considerably lower than that of the control species *E. grandis*. However, *F. sur* and *H. caffrum* exhibit patterns of fast growth rates with AUGC that is close to that of the control species, even though *E. grandis* has a faster growth rate. This is a revelation of the purposive use of exotic species for forestry as exotic species have considerably faster growth rates than indigenous tree species. Nonetheless, the two indigenous species should further be bred and developed for forestry purposes and restoration initiatives. This is attributed to their well-documented socio-economic benefits, notably the substantial nutritional and commercial value found in their fruits and other components (Pfukwa *et al*., 2020; Togdjim *et al*., 2023). These benefits encompass enhancements in biodiversity, the cultivation of fruits for consumption, and the utilization of leaves for medicinal purposes (Idahosa *et al*., 2020). The AUGC metric also plays an important role in the response of species to environmental factors and conditions and as a result, *S. birrea* exhibits its susceptibility to environmental stresses thus the lowest AUGC in terms of height as a measure of growth was observed in this study.

The correlation between height and rcd over the growing period was also assessed in this study, and a significant positive regression was obtained yielding a p-value of 0.012 and a very low R^2 of 18% (0.1788) when compared to R^2 of 78% (0.778) for the control species (Figure 4.3). This means that only 18% of the variation in the dependent variable can be explained by the regression model and this further indicates a very weak linear correlation between height and rcd among the five indigenous tree species in this study which could be attributed to other factors not taken into consideration such as spacing and competition (Bahru *et al*., 2018). Additionally, the positive but weak correlation between height and rcd was also observed in the field trial study conducted (Chapter three). In this this study, the weak correlation suggests that changes in one variable such as height does not consistently predict the other (rcd). this can be attributed to space, competition, pot size, and possibly even damaged soils, which may have an impact on tree development and growth (Wang *et al*., 2020).

4.5 Conclusion

Based on the findings of this study, it is evident that exotic species exhibit faster growth rates than indigenous species thus they were selected and are still used for forestry purposes more than indigenous species. In efforts of helping restoration of land, maximizing survival rate of species is important under greenhouse to maximize environmental and economic success. Additionally, to avoid the effect of transplant shock that generally affects plants under the greenhouse in the case of *S. birrea*, adequate water, and care during the first months of planting is required to reduce plant mortality.

Overall, this study highlights the potential of selecting indigenous tree species for forestry and restoration of anthropogenic lands as the species exhibit a high survival rate which is important for the restoration of degraded lands. Additionally, the study emphasizes the challenges and opportunities with using indigenous species in land restoration and allow for further exploration and development of indigenous tree species for the use of food, forestry and ecological restoration.

4.6 References

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Chapter Five

The Evaluation of Propagation Performance of Five Indigenous Tree Species from Cuttings in Kwazulu-Natal, South Africa

Abstract

Indigenous tree species have been underutilized in commercial settings because of their limited presence in consumer markets, limited cultivation, and lack of knowledge about propagation strategies. Generally, these species are propagated from seeds, which tends to introduce gene mixing which results in genetic improvement and diversity. Currently, limited studies have been conducted on the propagation of indigenous tree species from stem cutting. Therefore, this study investigates the use of vegetative propagation of indigenous tree species and aims to investigate the effect of different rooting hormones in the growth of different indigenous tree species from stem cuttings and investigate the feasibility of propagating indigenous tree species using cuttings. Four treatments (Seradix, Dip n Grow, Eco-T and no hormone/control) were tested on three cutting types (shoot tip, 1 node, and 2 nodes cutting) of five indigenous tree species (*Ficus sur*, *Harpephyllum caffrum*, *Sclerocarya birrea*, *Canthium inerme*, and *Trichilia emetica*) in a completely randomized block design under an automated misting propagation tunnel at the Institute of Commercial Forestry Research (ICFR) Nursery, UKZN, Pietermaritzburg. The data was recorded and subjected to analysis of variance (ANOVA). The findings show no significant difference in the rooting effect of four treatments on the five indigenous tree species tested. The highest survival, rooting, and sprouting percentages were exhibited at 12 weeks of planting on Eco-T, and the control samples propagated from *F. sur* accounted for 8.33% (survival), 16.67% (rooting), and 16% (sprouting). *H. caffrum* experienced the lowest survival, rooting, and sprouting percentages at the initial stages of growth accounting for zero percentages. Based on these findings, *F.* sur remains the only species showing potential growth and success for propagation from stem cuttings. To achieve better success, various factors need to be considered such as seasonal timing, irrigation, temperature, and moisture as well as the age of the source material. Future research can focus on the integration of rooting hormones and other vegetative propagation techniques to explore the development of indigenous tree species.

Keywords: Indigenous tree species; stem cuttings; rooting percentage; sprouting percentage; cutting types; rooting hormones.

5.1 Introduction

Indigenous tree species play a crucial role in supporting biodiversity, conserving natural resources, and providing economic benefits to communities (Lawes *et al*, 2004). Promoting the use and conservation of indigenous trees makes it possible to support rural communities and help sustainably manage their natural resources (Sharma *et al*., 2020). Historically, indigenous tree species have been underutilized in commercial settings because of their limited presence in consumer markets, limited cultivation and a lack of knowledge about propagation strategies (Smith *et al., 2022)*. This is due to the fact that exotic species have been favored, developed, and grown for commercial purposes in various countries (Farooq *et al.,* 2021; Smith *et al.,* 2022) as well as that they are fast growing (Arnoldi and Shackleton, 2021). However, commercial scale production of indigenous species has been gradually increasing over the past years as a result of a growing understanding of ecosystem function and value the indigenous species offer beyond cultural and aesthetic needs (Arnoldi and Shackleton, 2021; Smith *et al.,* 2022). Indigenous species play a role in promoting and sustaining natural biodiversity (Hill *et al*., 2020; Di Sacco *et al*., 2021). Additionally, indigenous tree species are usually adapted to local conditions such as climate, soil, and pests. This would require little external inputs such as irrigation and supplementary nutrients, and monitoring when grown under conducive conditions (Arnoldi and Shackleton, 2021). For example, most indigenous tree species like *Harpeohyllum caffrum*, *Sclerocarya birrea*¸ *Berchemia zeyheri*, and *Dovyalis caffra* require less to no frequent irrigation as it is very expensive. Thus, species adapted to local conditions should be prioritized (Nkosi *et al*., 2020).

Indigenous tree species are generally grown from seeds, and this method tends to introduce gene mixing which results in genetic improvement and diversity (Leakey *et al*., 2022). Mabizela *et al*. (2017) state that seed propagation does not always ensure the preservation of genetic variability. Also, obtaining high quality seeds from indigenous trees can sometimes be challenging as a result of seed dormancy e.g., *D. caffra* and *Canthium inerme* (Dharani *et al*., 2022). Hence, such species can be propagated from cuttings (Dharani *et al*., 2022). However, to expand markets and commercialize indigenous tree products, improving quality and uniformity is important and this can be done through vegetative propagation (Akinnifesi *et al*., 2006; Smith *et al.,* 2022). Vegetative propagation, especially cutting propagation can serve as an alternative in the absence of seeds and is considered to have added advantages through the production of uniformity, decreasing production time and maintaining specific genotypes (Akinnifesi *et al*., 2006). It is also considered as the ideal method to meet the demands and supply of uniform species in a growing industry of particular species (Mabizela *et al*., 2017). Various studies have been conducted on the vegetative propagation of a variety of species. For example, Smith *et al.* (2022) conducted a study exploring the propagation of ornamental species *Vachellia farnesiana* (Sweet acacia) from cuttings, and great success was achieved with survival percentages ranging from 53 to 73% from different treatments. Another study was conducted on cuttings of *Psidium guajava* (guava), in Asia by Kareem *et al*. (2016) where various indole-3-butyric acid (IBA) treatments were tested, and great success was achieved in cutting survival (58%) and sprouting (68%). The success of cutting propagation can depend on a range of factors, including the species, cutting type, rooting environment, and rooting hormone treatment (Kaushik and Shukla, 2020; Bahru and Derero, 2023).

Rooting hormones are plant growth regulators that can stimulate root development in cuttings and improve their chances of survival and growth and thus they play a role in seedling production of trees and crops (Rajan and Singh, 2021; Ruchitha and Poojashree, 2021). The compatibility of different rooting hormones on plants can vary depending on specific characteristics including the type of species, type of cutting, environmental conditions, and rooting hormone used (Rajan and Singh, 2021). In general, the hormones influence the growth of woody, herbaceous, and perennial plants (Rajan and Singh, 2021). Various plant growth regulators have been utilized in many crops and tree species to enhance the growth of cutting and improve the rooting ability of cuttings (Mabizela *et al*., 2017). These include indole-3butyric acid (IBA), naphthalene acetic acid (NAA), and indole-3-acetic acid (IAA) (Mabizela *et al*., 2017).

Commercially, the benefits of seedling production of indigenous tree species include the ability to produce large numbers of high-quality plants for reforestation and restoration projects, as well as for sale to nurseries. By propagating indigenous tree species, it becomes possible to conserve and protect these species, as well as to promote their use in urban and rural areas (Arnoldi and Shackleton, 2021; Smith *et al.,* 2022). To date, limited studies have been conducted on the propagation of indigenous tree species from stem cutting. To normalize the propagation of indigenous tree species from cuttings, this study investigates the use of vegetative propagation of indigenous tree species in a cost-effective way as a result that large commercial production of seedlings is costly. Hence the aim of this study was to test the effect of different rooting hormones in the growth of different indigenous tree species from stem cuttings and investigate the feasibility of propagating indigenous tree species using cuttings.

5.2 Materials and Methods

5.2.1 Experimental Design

Stem cuttings of five (5) indigenous tree species were taken from the Botanical Gardens and Arboretum at the University of KwaZulu-Natal, Pietermaritzburg. The experiment was carried out between November 2022 and January 2023 under an automated misting propagation tunnel at the Institute of Commercial Forestry Research (ICFR) Nursery, UKZN, Pietermaritzburg. The experiment was set up in a 4 x 3 x 5 x 4 completely randomized block design constituted by 4 treatments (Seradix, Dip n Grow, Eco-T, and no hormone/control), 3 cutting types (shoot tip, 1 node, and 2 nodes cutting), 5 indigenous tree species (*Ficus sur*, *Harpephyllum caffrum*, *Sclerocarya birrea*, *Canthium inerme*, and *Trichilia emetica*), and 4 replications.

5.2.2 Preparation of Cuttings and Application of Treatment

Cuttings used in this experiment were taken from the cuttings collected and selected based on the size and availability of nodes and shoot tips. The cuttings were then trimmed according to it set of cuttings (1 node, 2 nodes, and shoot tip), as well as a control set. The leaves on many cuttings were cut out or trimmed as well. Following the preparation of the cuttings, the prescribed treatment was administered as instructed. This involved dipping the cuttings in Seradix (which contains a singular active ingredient, indole-3-butyric acid (IBA)), Eco-T (containing the active ingredient derived from the fungus *Trichoderma asperillum*), and Dip n Grow (which includes both indole-3-butyric acid (IBA) and 1-Napthaleneacetic acid (NAA)). The control set was cuttings of each species that were not treated or dipped. After the treatment application, the cuttings were placed under a rooting tunnel and monitored.

5.2.3 Data Collection and Statistical Analysis

Data collection commenced at the time of planting and continued at two, six, and twelve weeks thereafter, allowing for comprehensive growth and development of the cuttings over time. Data was collected on surviving cutting (rooted and sprouted) and recorded on a Microsoft Excel spreadsheet to obtain means and standard deviation of shoots and the interaction of cutting type and rooting hormone. Statistical analysis of all data was completed using GenStat 23rd edition. The data was subjected to statistical analysis of variance (ANOVA) to determine differences between treatments, and Fisher's Unprotected Least Significant Difference Test was used ($P = 0.05$).

5.3 Results

5.3.1 The Effect of Different Rooting Treatments on the Survival Performance of Five Indigenous Tree Stem Cuttings in a Rooting Tunnel Over Twelve Weeks

The survival percentage of indigenous tree stem cuttings (1 node, 2 nodes, and shoot cuttings) planted in a rooting tunnel and monitored for 12 weeks is presented in Figure 4.1. The number of cuttings that survived after 12 weeks of growth was counted. Statistically, the hormonal treatments had no significant effect on the survival of cuttings with p = 0.743 and there was no significant difference between interactions (cutting type and rooting hormone) in terms of cutting survival with p = 0.922 (Appendix 5, Table 5.1). After 2 weeks of planting, only 4 out of 5 indigenous tree species had the highest survival above ranging from 85 to 98%, and the highest mortality was observed in *H. caffrum* with zero cutting survival. Gradually, all cuttings decreased in survival, and after 12 weeks only *F. sur* cuttings exhibited a survival percentage of 8.33%.

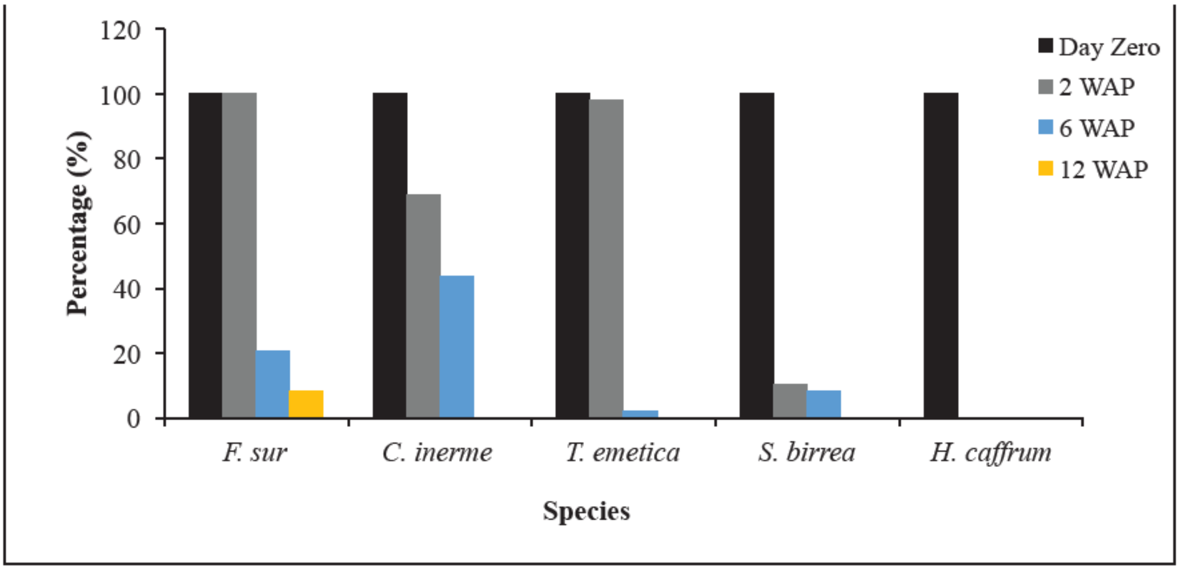

Figure 5.3: Survival performance of five indigenous tree species cutting in a rooting tunnel over 12 weeks.

5.3.2 Effect of Different Rooting Treatments on the Growth Response of Five Indigenous Tree Stem Cuttings in a Rooting Tunnel over 12 weeks

After 12 weeks of planting, the mortality rate of indigenous tree cutting was very high and only one species survived and was observed to exhibit the highest growth in only two treatments (control and Eco-T). No treatment containing active ingredients IBA and NAA affected growth.

Statistically, no hormonal treatment was found significant amongst all four investigated treatments (p = 0.090). The surviving species at 12 WAP of *F. sur* cuttings treated with Eco-T and the control sample exhibited an average change in height of 10.29 and 18.29 mm, respectively (Figure 5.2).

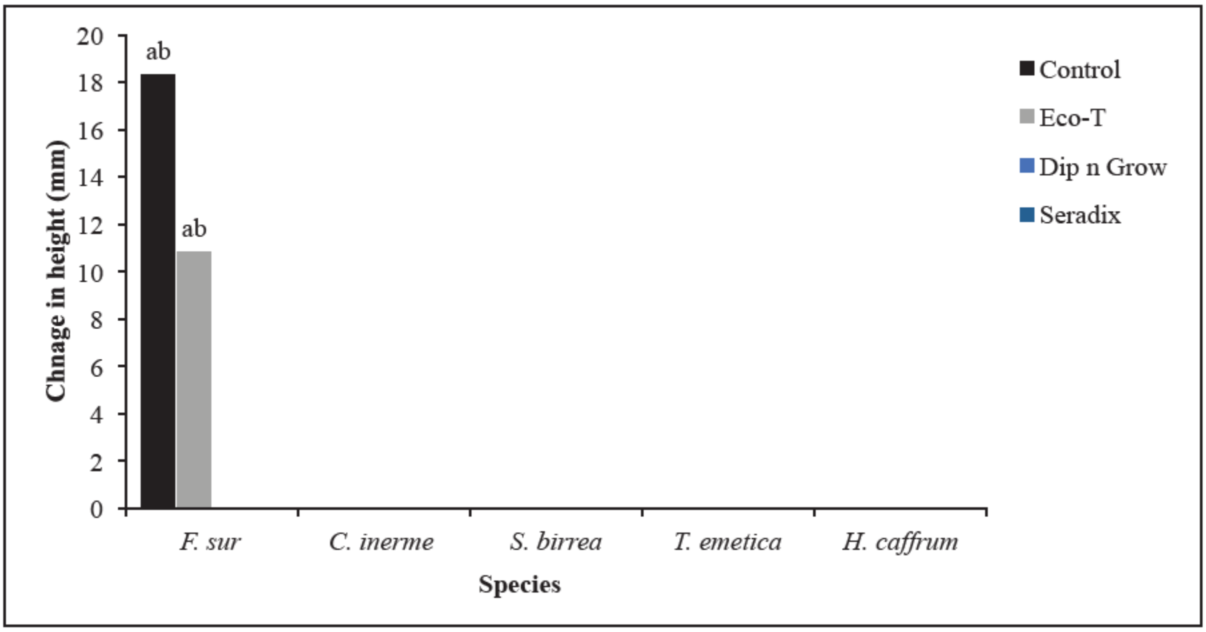

Figure 5.4: Effect of different rooting treatments vegetative growth of height of indigenous tree cuttings grown in rooting tunnel over a period of 12 weeks.

5.4.3 The Effect of Different Rooting Treatments on Rooting and Sprouting Percentage of Indigenous Tree Species Stem Cuttings

There are no significant differences in rooting and sprouting percentage of indigenous tree stem cuttings (P > 0.05) (Table 5.2). The different rooting treatments did not have any effect on the rooting and sprouting of indigenous tree cuttings. The overall mean rooting and sprouting percentage of all cutting samples at 12 weeks after planting (WAP) was observed to be 16.67 and 16%, respectively. At 6 WAP, sprouting peaked for three species i.e., *C. inerme*, *F. sur,* and *S. birrea* accounting for an overall mean sprouting percentage of 24.16%. Additionally, only 16% of *Ficus sur* cuttings that sprouted were treated with Eco-T, and the control sample (untreated) at 12 WAP.

Table 5.4: The effect of different rooting treatments on rooting and sprouting percentage of five indigenous tree species stem cuttings. (n=240; 48 per species, 12 per treatment).

Species	**Treatments**	**Rooting %**			**Sprouting%**		
		2WAP	**6WAP**	**12WAP**	**2WAP**	**6WAP**	**12WAP**
C. inerme	Control	0.00a	0.00a	0.00a	0.00a	41.67a	0.00a
	Eco-T	0.00a	0.00a	0.00a	0.00a	25.00b	0.00a
	Dip n Grow	0.00a	0.00a	0.00a	0.00a	41.67a	0.00a
	Seradix	0.00a	0.00a	0.00a	0.00a	33.33b	0.00a
F. sur	Control	0.00a	0.00a	16.67a	0.00a	33.33b	16.00a
	Eco-T	0.00a	0.00a	16.67a	0.00a	25.00b	16.00a
	Dip n Grow	0.00a	0.00a	0.00a	0.00a	8.33d	0.00a
	Seradix	0.00a	0.00a	0.00a	0.00a	8.33d	0.00a
T. emetics	Control	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
	Eco-T	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
	Dip n Grow	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
	Seradix	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
H. caffrum	Control	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
	Eco-T	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
	Dip n Grow	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
	Seradix	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
S. birrea	Control	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
	Eco-T	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
	Dip n Grow	0.00a	0.00a	0.00a	0.00a	8.33d	0.00a
	Seradix	0.00a	0.00a	0.00a	0.00a	16.67a	0.00a
	Mean	0.00a	0.00a	16.67a	0.00a	24.16b	16.00a
	P value	-	-	0.744	-	0.620	0.741
	LSD	-	-	13.85	-	15.46	10.83
	CV%	-	-	53.3	-	29.1	54.1

Mean percentages with the same letters in the same column indicate no significant differences (P = 0.05).

5.5 Discussion

The survival and mortality percentage of indigenous tree cuttings under ideal conditions indicate the difficulty and challenges associated with the propagation of indigenous tree species. This study attempted to use different rooting hormones to improve the growth of indigenous tree cuttings and no significance was found to on the growth and survival of the cuttings. Such efforts were consistent with other studies that achieved success in propagating tree species through the utilization of vegetative propagation (Smith *et al*., 2022; Bahru *et al*., 2023). However, little success was achieved in this study as the initial high survival of species after 2 weeks was observed. Only 4 out 5 indigenous tree species survived with a rate of 85 to 98%, and the highest mortality was observed in *H. caffrum* with zero cutting survival. Gradually, all cuttings decreased in survival, and after 12 weeks only *F. sur* cuttings exhibited a survival percentage of 8.33%. Such fluctuations in the survival rate of indigenous tree species could indicate varying susceptibilities to several factors and stressors that affect the species. These factors include species, cutting type, rooting environment, rooting hormone treatment, age of the source material and the season of growing, as well as the irrigation and environmental conditions such as temperature and moisture (Mabizela *et al,* 2017; Bahru *et al*., 2023). In comparison with the commercial exotic *Eucalyptus* species, great success was achieved in a study by Nwigwe *et al*. (2023) which reported a survival rate of the cuttings to be greater than 75% after eight weeks of growth. Additionally, Nwigwe *et al*. (2023) suggest that achieving significant propagation success with cuttings requires testing the rooting compatibility of those species. This is shown by the low survival rate of various *Eucalyptus* clones accounting for less than 50% suggesting that the survival is dependent on the type of species that is treated as well as the rooting hormone used (Sarpong *et al*., 2020). Similarly, to the current study, the compatibility of rooting hormones with the type of species and cutting type used could explain the low survival rate of indigenous tree stem cuttings.

In general, indigenous tree species investigated in this study suffered a gradual increase in mortality throughout the study. The overall survival percentage for indigenous tree stem cuttings out of 240 samples was 2% at the end of the growing period and only one treatment (Eco-T) showed the highest survival percentage than the control sample. This could be attributed to the environmental conditions inside the rooting tunnel even though temperature and moisture were consistent throughout the growing period (Kareem *et al*., 2016). However, the over-application of misting irrigation possibly affected the survival of the species stem cuttings. This saturation of the rooting medium probably led to waterlogging depriving the cutting samples of enough oxygen thus creating room for root and cutting sample rot (Walne and Reddy, 2021). As a result, the low survival percentage correlated with the low development of roots and sprouts by the indigenous tree stem cuttings which also impacted the growth performance of those species.

The effect of different rooting treatments on the growth performance of indigenous tree species stem cuttings was investigated in this study. There was no significant difference found between the treatment on the growth of indigenous tree stem cuttings ($P > 0.05$). At 12 WAP only *Ficus sur* cuttings treated with Eco-T and the control sample exhibited an average change in height of 10.29 and 18.29 mm, respectively. The growth of *Ficus sur* can be attributed to the impact of adventitious roots and the trunk system, which actively participate in the absorption and distribution of nutrients and hormones throughout the plant (Li, 2022). However, Eco-T is known and considered a beneficial plant growth-promoting fungus that plays a role in root development and growth of plants through the formation of mutual endophytic interactions with a wide range of plant species (Eman *et al.*, 2023).

The effect of different rooting treatments on rooting and sprouting percentage of indigenous tree species stem cuttings was also investigated in this study and no significant effect by the rooting treatments was observed in roots and sprout development ($P > 0.05$). The results show the mean rooting and sprouting percentage of *Ficus sur* cutting samples delivered by Eco-T treatment, and the control sample at 12 WAP was observed to be 16.67 and 16%, respectively. However, at 6 WAP, sprouting peaked for three species i.e., *C. inerme*, *F. sur,* and *S. birrea* accounting for an overall mean sprouting percentage of 24.16%. This could suggest that the optimal time for out-planting of indigenous tree stem cutting is 6 weeks. A study conducted in South Africa, by Laubscher (2000) on indigenous tree species (*Podocarpus falcatus*, *F. sur*, and *Syzygium cordatum*), shows the success of propagating indigenous tree species from cutting and the results show that the rooting success of these species ranged between 60 to 85%. Mabizela *et al.* (2017) suggest that the period of the year in which cuttings are taken, and seasonal timing can also affect the rooting of stem cuttings. According to Simons and Leakey (2004), the optimal success in vegetative propagation is attainable when species can be propagated from early or juvenile tissues, with success rates ranging from 75% to 90% observed in the case of *Prunus africana* cuttings.

In contrast with the findings of the current study, a study by Ibrahim *et al.* (2015) suggests that usually rooting hormones that contain plant growth regulators (PGRs) including IAA, IBA, and

NAA would ideally accelerate the development of roots, increase rooting and sprouting percentage. Additionally, the very low rooting percentage in indigenous tree stem cuttings treated with Dip and Grow rooting hormone regardless of the cutting type treatments could be attributed to the presence of plant growth regulator NAA (Ibrahim *et al*., 2015). In studies where NAA is used independently as a rooting hormone, a low rooting percentage is observed for example, *Vachellia farnesiana* (Smith *et al.,* 2023) and *Cyclopia subternata* (Mabizela *et al*., 2017). Lastly, the high survival, rooting, and sprouting percentage in the control sample suggests that auxin and PGRs application may not necessarily be the catalytic factor in influencing root and sprout development in indigenous tree species (Andre Patrick *et al*., 2020).

5.6 Conclusion

In this current study, we attempted to grow indigenous tree species from stem cutting of three cutting types (1 node, 2 nodes, and shoots) with the aim of utilizing different rooting hormones as an enhancement on the growth of the species. This study demonstrated the challenges and lack of information regarding the vegetative propagation of indigenous tree species from cuttings. Based on the findings of this study regardless of the little success obtained, *F. sur* remains the only species that is consistent in showing potential growth and success for propagation. It also showed the highest survival, rooting, and sprouting percentage at the end of the growing period. Despite, the findings from this study due to several factors such as oversaturation on growing medium, temperature, and moisture, various studies suggest that the compatibility of rooting hormones with the type of species and cutting type used is necessary to yield great propagation success (Sarpong *et al*., 2020; Nwigwe *et al*., 2023;). This is because rooting hormones are considered useful in cutting propagation to stimulate and enhance the rooting process of cutting. Nonetheless, further development and research are needed to explore the potential of *F. sur* as well as other important indigenous tree species that can add value in forestry and be utilized for commercial purposes. For future research, the integration of rooting hormones and other vegetative propagation techniques can be explored for the development of indigenous tree species.

5.7 References

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Chapter Six

Thesis Overview of The Major Findings and Implications

6.1 Introduction

In South Africa forestry is mostly made up of non-indigenous trees and many indigenous trees have lost their natural habitat to the expansion of exotic plantations that has been occurring over decades (Kaptein *et al*., 2023). The expansion of plantation forests in South Africa now covers more than 1% of the total landmass compared to natural forests (Odebiri *et al*., 2020). These plantation forests are mainly made up of exotic monocultures that tend to drive biodiversity away, they become invasive and then begin to alter natural ecosystems (Odebiri *et al*., 2020). Additionally, due to their greater growth forms than indigenous species, they are mostly preferred for commercial forestry (Kaptein *et al*., 2023). However, Di Sacco *et al.* (2021) suggest that planting indigenous tree species can help in improving biodiversity and conserve natural ecosystems their associated resources. Important indigenous trees such as *Dovyalis caffra*, *Vangueria infausta*, *Sclerocarya birrea*, *Berchemia zeyheri*, *Harpephyllum Caffrum*, *Trichilia emetica, Ficus sur* and *Strychnos spinosa* (Nkosi *et* al., 2020; Omotoya and Aremu, 2020) can also be grown in communities at a commercial level as a supplement to mainstream income sources, to support livelihoods and the well-being of those communities (Shackleton and Shackleton, 2006). These species are recognized for their nutritional and medicinal value. They are rich in various sources of vitamins, minerals, protein, and valuable phytochemicals, and can be utilized as therapeutic remedies (Omotoya and Aremu, 2020). Hence, there is a huge need to explore the potential of these species and to develop them for nutritional and commercial qualities for them to be viable for commercial markets (Omotoya and Aremu, 2020). In essence, by elevating these species' profile and value, they can become attractive commodities in commercial markets, providing both economic opportunities and preserving cultural and ecological heritage (Ramaano, 2022). The main aim of the project was to investigate the use of indigenous trees for commercial forestry, community development, as well as land restoration. This aim was achieved by assessing and evaluating the growth and survival of indigenous species through the application of propagation methods and the integration of PGPMs.

The aim was further achieved by the following objectives:

i. To conduct a literature search and then document existing scientific literature on the use of indigenous trees in forestry as a build-up source for the literature review.

ii. To conduct a social study evaluating the indigenous knowledge of selected communities to assess their knowledge of indigenous tree species in terms of importance and utilization.
iii. To conduct a basic growth trial using commercial forestry skills and approaches. A field trial was established using forestry techniques to conduct the trial, at a community nursery in the Ntshongweni area.
iv. To conduct a pot trial of indigenous vs commercial exotic tree varieties under greenhouse conditions using soils collected from degraded land.
v. To conduct propagation studies of indigenous trees from stem cuttings for the potential purpose of producing seedlings and cuttings, cost-effectively.

The purpose of this chapter is to review the major objectives of this project and their major findings, implications and identify future research needs, and finally make recommendations.

6.2 Indigenous Knowledge and Documentation of the Use and Importance of Indigenous Trees in the eThekwini Area of KwaZulu-Natal Province

This study seeks to contribute to the documentation and preservation of indigenous knowledge surrounding the use and significance of indigenous trees in three peri-urban communities under eThekwini Metro, as well as to identify possible indigenous tree species for forestry based on community preferences. This was achieved by answering questions based on which indigenous tree species and products are commonly used and harvested in each study area, as well as capturing local tree species preferences.

6.2.1 Major Findings:

- A total of 21 indigenous tree species were mentioned in this study along with their perceived uses and harvested products across the three sites.
- A total of 12 species were reported and utilized in either all three or two communities including species such as *A. adianthifolia*, *A. karroo*, *C. inerme*, and *H. caffrum* and only four species were used in all three communities along with their uses i.e., *S. birrea*, *V. infausta*, *T. emetica*, and *P. africana.*
- 60% of the participants usually utilized medicinal and fruit products from indigenous tree species and only 35% utilized gum and timber harvest from the species.
- Participants reported that some species are protected because they have a certain value to the community, either spiritual or commercial value for example *V. sieberiana* (Paperbark

thorn; medicinal value) and *Z. mucronata* (Buffalo thorn; spiritual importance or used in death occurrences).

- Most commercial value of indigenous tree species is from medicinal products that are extracted mostly from Paperbark thorn and Marula that are sold for medicinal purposes, which is where the market is open.

6.2.2 Implications

The identification of indigenous tree species along with their associated resources in peri-urban areas highlights rich cultural and traditional knowledge within peri-urban communities. It emphasizes the species' cultural significance, medicinal and commercial values, and beliefs held by the communities about particular species that are deemed useful and important. This shows that it is important to identify and select specific species that are commonly utilized across communities and have a potential for commercialization, potentially creating income sources for local communities. Thus, most reports and focus on this study are on medicinal and fruit products which suggest a market niche worth further exploring. Furthermore, the findings suggest that future studies should continue to integrate indigenous knowledge into research methodologies, recognizing the socio-economic and cultural importance of these tree species.

6.3 Field Establishment of Indigenous Tree Species Using *Trichoderma* Asperellum at Ntshongweni, Durban, KwaZulu-Natal

The aim of this research was to conduct a basic growth trial using commercial forestry skills and approaches and to investigate the impact of a plant growth-promoting fungus, specifically a strain of *T. asperellum*, on the survival and growth of the seedlings under field conditions.

6.3.1 Major Findings

- Only *H. caffrum* (100%) demonstrated the highest survival rate of the five-tree species. Although no significant difference was observed for survival between the species.
- The seedlings of *F. sur* grew the fastest (33.13 cm) amongst the five-tree species however, no significant difference was observed between the species.
- The study also established a moderate (R^2 = 39%), and significantly positive correlation (P < 0.000237), between tree height and root collar diameter.
- The application of *Trichoderma* treatment as a drench did not have a significant effect on tree height and root collar diameter growth (P = 0.391 and 0.933, respectively).

6.3.2 Implications

The highest survival rate (100%) observed for *H. caffrum* indicate its resilience and adaptability to the local conditions. Also, the fastest growth displayed by *F. sur* among the studied species (33.13 cm) suggests its potential for development, which can be crucial in restoration efforts or commercialization potential. To choose species appropriate for commercial planting or reforestation initiatives, it is crucial to ascertain their unique characteristics and rates of survival through experimental growth trials because they can reveal species-specific traits. Under field conditions *T. asperellum* treatment did not have any significant effect on tree height and root collar diameter growth. This suggests that further investigation may be needed to the effectiveness of *T. asperellum* in the growth of indigenous tree species.

6.4 Pot Trial of Indigenous Trees Against Commercial Exotic Species Using Degraded Soils with Incorporation of Trichoderma asperellum, Under Greenhouse Conditions

This chapter investigated the use of plant growth-promoting fungus, specifically *T. asperellum*, on the survival and growth of the indigenous tree seedlings compared to a control species *E. grandis* which was not treated on degraded soils, under greenhouse conditions.

6.4.1 Major Findings

- All indigenous tree species exhibited survival rate of 100% except for *S. birrea* with a survival percentage between 67 and 92% in both treated and untreated samples.
- The seedling of *F. sur* grew faster than the rest with 48.8 cm in height but not as compared to the control species accounting for 99.34 cm.
- Statistically, the AUGC as a measure of growth was not significant in both height and rcd accounting for P = 0.635 and 0.942, respectively. However, only *H. caffrum* and *F. sur* exhibit the highest AUGC for height and rcd.
- A weak positive correlation between height and root collar diameter was established in this study for indigenous tree species with p = 0.012, R^2 = 18% compared to a strong correlation of R^2 = 78% for the control species *E. grandis*.
- The incorporation of *Trichoderma* treatment in growth showed no significant effect on tree height and root collar diameter P =0.838 and P = 0.556), respectively

6.4.2 Implications

Similar to the above chapter, the 100% survival rate observed in most indigenous tree species highlight their potential for adaptation and resilience under greenhouse conditions, as well as in anthropogenic soils. factors critical for afforestation and reforestation initiatives. This is asserted by the rapid growth of *F. sur* (48.8 cm) indicating its potential need for further development, but the comparison with the control species (*E. grandis*) highlights the reason for exotic commercial forestry which mainly involves species selection based on growth rates. In addition, the non-significant effect of *T. asperellum* in growth of height and root collar diameter, suggest further research could explore different application methods and concentrations to optimize its effectiveness in promoting growth.

6.5 The Evaluation of Propagation Performance of Five Indigenous Tree Species from Cuttings in Kwazulu-Natal, South Africa

To investigate the effect of different rooting hormones in the growth of different indigenous tree species stem cuttings and investigate the feasibility of propagating indigenous tree species using three types of cuttings.

6.5.1 Major Findings

- The findings show no significant difference in the rooting effect of four treatments on the five indigenous tree species tested.
- The survival, rooting, and sprouting percentages were exhibited at 12 weeks of planting on Eco-T, and the control samples propagated from *Ficus sur* accounted for 8.33% (survival), 16.67% (rooting), and 16% (sprouting).
- However, at 6 WAP sprouting peaked for three species i.e., *C. inerme*, *F. sur,* and *S. birrea* accounting for 24.16%
- *H. caffrum* experienced the lowest survival, rooting, and sprouting percentages at the initial stages of growth accounting for zero percentages.
- *F. sur* remains the only species showing potential growth and success for propagation from stem cuttings.

6.5.2 Implications

The lack of significant difference and the low survival, rooting and sprouting rate indicate the challenge with regards to the compatibility of rooting hormones, species and cutting type. Optimal propagation success was observed at week 6 after planting for three species which could indicate the optimal period for specific species propagated from stem cuttings. Also, the survival and rooting of *F. sur* at 12 WAP highlights the species' resilience and further potential for mass production of seedlings from cuttings after successful propagation. This suggests that *F. sur* can be prioritized in indigenous tree species propagation, conservation, and reforestation initiatives. While the study provides valuable insights into the early stages of propagation, further research is needed to assess long-term establishment and growth of the propagated trees. In addition. understanding the dynamics of different propagation stages over time is valuable for optimizing propagation protocols.

6.6 Recommendations for Future Studies

It is recommended that such or similar studies be undertaken as long-term studies to assess the long-term growth and viability of indigenous tree species. Long-term studies can provide insights into the adaptability and resilience of these species over time. Also, investigations on alternative growth-enhancing treatments such as mycorrhizal fungi and other *Trichoderma* strains or approaches that may be more effective for indigenous species' growth would be ideal. Additionally, the employment of nutrient analysis to assess nutrient availability can provide insights into nutrient uptake and deficiencies. Lastly, the compatibility of rooting hormones with the type of species and cutting types, as well as other vegetative propagation techniques can be explored for the development of indigenous tree species. Implementing the recommendations derived from these implications can contribute to more effective and sustainable practices in the fields of forestry, conservation, and agriculture.

6.6.1 Future Research and Development Actions

- Investigate the potential and feasibility of specific indigenous tree species for urban forestry, greening, and agriculture.
- Explore the social and ecological implications (multi-use and cultural desirability) of indigenous tree species in the replacement of invasive species and develop strategies for mitigation.
- Conduct in-depth studies on the development and growth patterns of indigenous tree species by focusing on AUGC and WAP as important benchmarks for indigenous species.
- Explore community-based conservation and management strategies for sustaining the cultural, economic, and ecological significance of indigenous tree species.

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Appendices

Appendix 2-A

Ntshongweni Community: Focus Group Survey

Number of People interviewed: 8

Guideline Questions for The Participants

1. What are the most important trees around the community and their uses?
   - *The most used products extracted from indigenous trees is medicinal products, mostly from leaves and bark extracts, as well as edible fruits from fruit producing trees.*
2. What is their propagation method?
   - *The trees are propagated from seeds that are gathered from the wild and planted in bottles or dishes.*
3. Are there any propagation challenges and field challenges (pests and diseases)?
   - *There are no unusual challenges except for seeds not propagating properly in their media, or seedling dying at an early stage or not emerging from the soil like other seedlings.*
   - *There are no known diseases or pests that affect the trees at early stages.*
4. What are their reasons for propagating and planting these trees.
   - *The trees are planted for landscaping, or just for the reason of having big trees around the household and community. The trees are also planted because they can provide food (fruits) for children to enjoy as well as shade or shelter.*

Appendix 2-B

EMaphephetheni Community Survey: One - On - One interviews.

No. Of people interviewed: 2.

Guideline questions for tree growers/Treepreneurs

1. Which are the most planted/preferred indigenous tree species? Yiziphi izihlahla zomdabu ezibalulekile nezithandwa kakhulu?
   - *umKhiwane, isiHlakothi (harvested for building poles), uMganu, iNhlungunyemba, umLahlankosi (medicine), umKhamba (medicine), umSimbithi, iPhahla (medicine), umHlalumakhwaba*
2. Which are the most economically important indigenous trees? Yiziphi izihlahla zomdabu ezibaluleke kakhulu kwezomnotho?
   - *umKhamba and umGanu tree barks are extracted and sold for medicine.*

3. How do you propagate the trees and what propagation challenges do you encounter? Uzilima kanjani izihlahla futhi yiziphi izinselelo noma izinkinga zokutshala ohlangabenzan nazo? Izifo zezitshalo, izinambuzane.

- *We are given a tree list which we have to collect seeds for, after we have collected the seeds we propagate them on bath dishes and then at emergence stage we transfer them to bottles. The bottles need to have holes at the bottom to allow water drainage and for the tree and roots to breathe and grow well. Frequent watering is required for seedling to emerge and I nurture them just as like a young baby.*
- *There are no pests or any disease that I know of.*

4. Do the cultivated indigenous trees have any value to the community? Ngabe izihlahla zomdabu ezitshalwe zinenani elithile emphakathini

- *The trees around the community are protected and they are not supposed to be cut down with no reason.*

5. What are the forest products you normally harvest from forests? Firewood, timber, poles, medicine, fruits

   Iyiphi imikhiqizo yehlathi ovame ukuyivuna emahlathini? Izinkuni, izingodo, izigxobo, imithi, izithelo.

- *Poles and firewood – isiHlakothi umSimbithi*
- *Medicine – umGanu, umKhamba*

6. Which forest product is harvested the most?

   Yimuphi ukhiqizo wehlathi ovunwa kakhulu kulokho okubaliwe

- *Bark for medicine – umKhamba, umGanu, iNyazangoma, umKhuhlu*

7. Which indigenous trees would you want around the community and for what reason?

   Yiziphi izihlahla zomdabu ongazifuna emphakathini futhi ngasiphi isizathu - *umGwenya, uSingalwesalukazi (are not common around the community)*

8. Which commercial tree species would you want around the community?

   Yiziphi izihlahla zehlathi zentengiso ongathanda zibe khona emphakathini.

- *umDoni wehlathi (for medicine and fruits), umTulwa, umHlali, and umThunduluka for delicious fruits (because these trees are scarce or hard to find around the community).*
- *And no to alien trees because they block our preferred trees from growing.*

9. Does the forest belong to the community, government or municipality or tribal authority?

   Ngabe ihlathi elomphakathi, uhlumeni, noma umasipala

- *Tribal authority*

10. Are there any trees that are protected from being harvested? And why

    Ngabe zikhona izihlahla ezivikeliwe noma okungavunyelwe ukuthi zithintwe noma zivunwe noma zisetshenziwe.

- *umLahlankosi is protected, is not to be touched because it only used for funerals.*

Appendix 2-C

Community Qualitative Survey - Buffelsdraai

Table 5.1: The number of participants utilizing indigenous tree species along with their associated uses in Buffelsdraai community. (N=10).

Common Names	Common Uses	Not used	Rarely used	Averagely used	Mostly used	Sum
Marula	Bark and leaves (medicine)	1	3	1	5	10
	Edible fruits	0	4	2	4	10
	Timber (Furniture)	1	2	3	4	10
Flat Crown	Bark (medicine)	1	4	1	4	10
	Shade	3	1	3	3	10
Fever Tree	Bark (medicine)	1	1	2	3	7
	Timber	2	1	3	1	7
River Bushwillow	Roots (medicine)	2	3	2	2	9
	Building poles	1	4	1	2	8
	Poles	3	2	2	2	9
Natal Mahogany	Bark (medicine)	1	1	3	3	8
	Timber (Furniture)	2	3	2	2	9
Sugar bush	Bark (medicine)	2	0	2	2	6
Broom Cluster fig	Edible fruits	1	2	4	3	10
	Wood (drums)	2	2	2	4	10
African Medlar	Edible fruits	2	2	1	4	9
	Bark and leaves (medicine)	4	0	3	2	9
Wild Plum	Edible fruits	2	2	1	4	9
	Bark (medicine)	2	3	1	3	9
	Timber	2	2	1	4	9
Red Stinkwood/African almond	Bark (medicine)	0	2	4	3	9
	Wood (furniture)	1	2	3	3	9
Water-berry	Edible fruits	0	1	2	7	10

	Bark (medicine)	1	3	0	5	9
Umzimbeet	Poles	3	1	3	2	9
	Firewood	2	2	1	3	8
	Wood (furniture)	2	3	1	4	10
Forest silver-oak	Poles	2	1	1	3	7
	Firewood	1	1	3	3	8
White Stinkwood	Timber	4	2	0	3	9
Sweet Thorn	Bark and leaves (medicine)	1	2	1	1	5
	Bark (gum)	2	2	2	0	6
Buffalo Thorn	Roots, leaves and bark (medicine)	0	0	3	4	7
	Edible fruits	5	1	0	1	7
	Timber	5	1	0	1	7
Turkey-berry	Leaves (medicine)	1	2	2	5	10
	Edible fruits	1	2	2	4	9
	Wood (furniture)	1	3	3	3	10

Table 2.1: Percentage of usage of indigenous tree species by participants reported in all the three sites.

Species	**Used (%)**	**Not used (%)**
Paperbark thorn	10	90
African wintersweet	10	90
umHlalumakhwaba	10	90
White Stinkwood	30	70
Buffalo Thorn	35	65
Fever Tree	40	60
Sweet Thorn	40	60
Water-berry	45	55
Umzimbeet	50	50
Forest silver-oak	52	48
Turkey-berry	55	45
Flat Crown	80	20
River Bushwillow	80	20

Sugar bush	80	20
Wild Plum	80	20
African Medlar	85	15
Blunt-leaved current	90	10
Broom Cluster fig	92	8
Natal Mahogany	92	8
Red Stinkwood	95	5
Marula	95	5

Table 2.2: Indigenous tree species uses reported by participants across three sites.

Common Uses	**No. of users (n=20)**	**% of users**
Medicine (bark, leaves, roots)	12	60
Edible fruits	12	60
Poles	11	55
Furniture	10	50
Firewood	9	45
Drums	8	40
Shade	7	35
Timber	7	35
Gum (bark)	6	30

Appendix 3

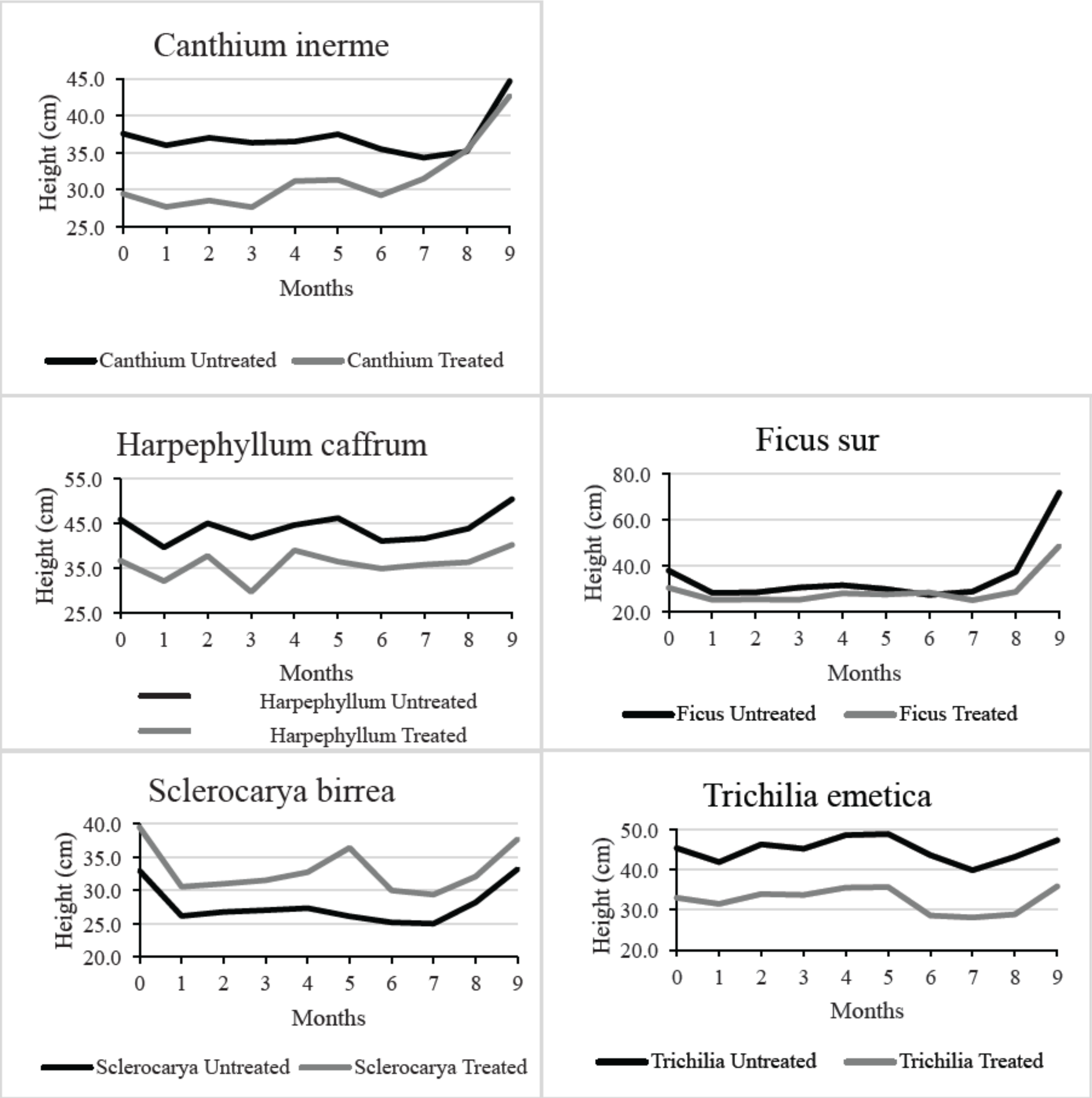

Figure 3.1: Overall growth of height of five indigenous species over the period of 10 months (March 2022 – Feb 2023)

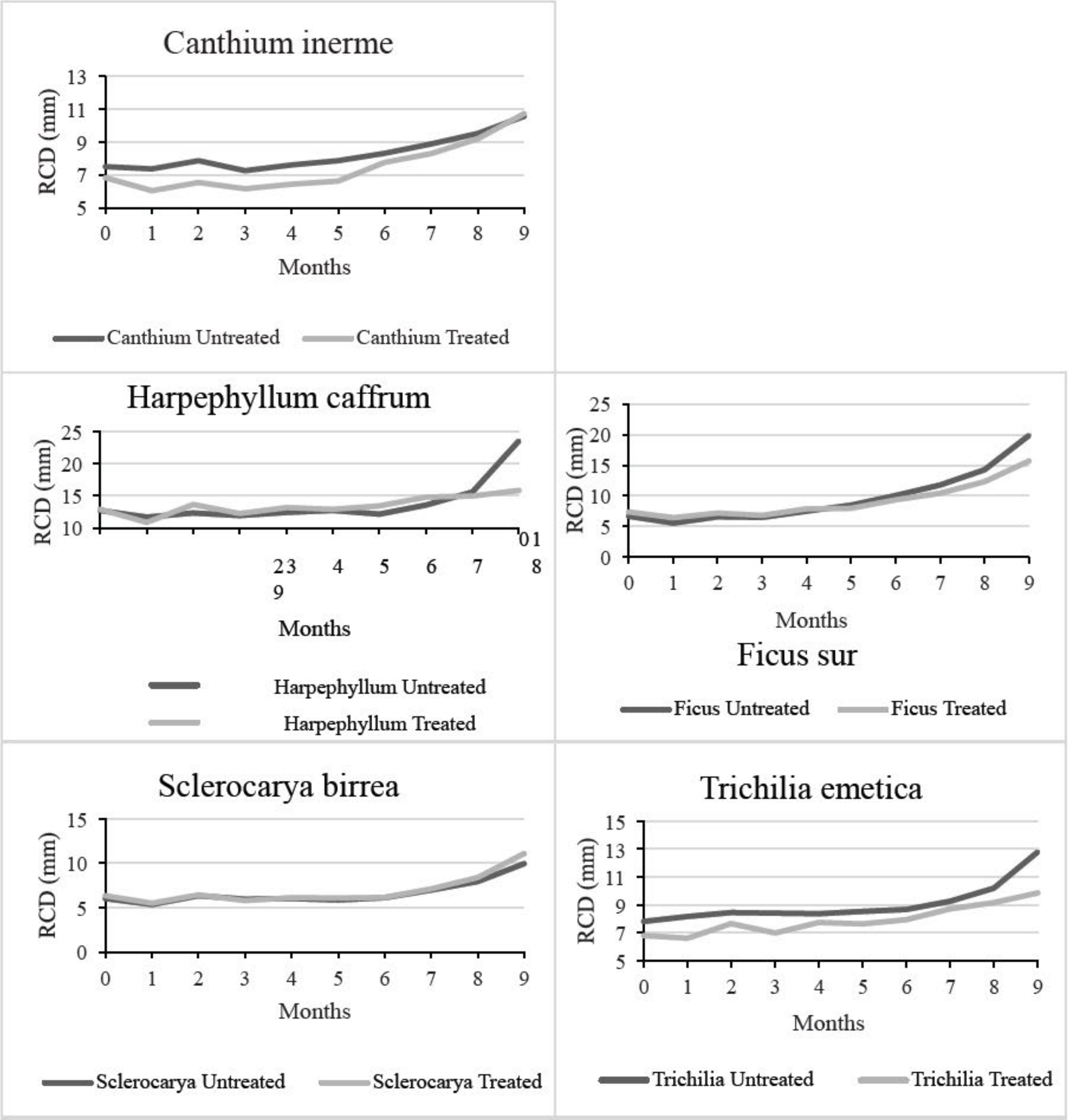

Figure 3.2: Overall growth of RCD of five indigenous species over the period of 10 months (March 2022 – Feb 2023)

Table 3.1: The effect of growth-promoting fungus *Trichoderma* on the AUGC of height and RCD. (Treatment 0 = Untreated, and 1 = Treated)

Species	Treatment (0/1)	Replication	AUGC (Height)	AUGC (RCD)
Canthium	0	1	12538.35	3.074
	0	2	13190.88	2.86
	0	3	9465.83	2.09
Canthium	1	1	7537.88	2.009
	1	2	8933.6	2.337
	1	3	13998.85	2.946
Ficus	0	1	9001.1	2.995
	0	2	13986.97	3.608
	0	3	11390.19	3.284
Ficus	1	1	8003.13	2.995
	1	2	7991.75	3.608
	1	3	12055.83	3.284
Harpephyllum	0	1	19938.75	5.709
	0	2	12036.38	3.839
	0	3	9926.48	3.941
Harpephyllum	1	1	11719	5.709
	1	2	8747.28	3.839
	1	3	13743.9	3.941
Sclerocarya	0	1	8622.83	2.016
	0	2	8738.93	2.429
	0	3	9016.03	2.007
Sclerocarya	1	1	10015.38	2.016
	1	2	9529.58	2.429
	1	3	11573.6	2.007
Trichilia	0	1	16386.3	3.609
	0	2	18684.38	3.243
	0	3	7687.68	1.971
Trichilia	1	1	9732.68	3.008
	1	2	10639.96	2.461
	1	3	10304.86	2.235

P- value		0.141	0.595
CV (%)		27.8	20.5

Appendix 4

Table 4.1: The effect of growth-promoting fungus *Trichoderma* on the AUGC of height and RCD of indigenous species vs control under greenhouse conditions. (Treatment 0 = Untreated, and 1 = Treated)

Species	**Treatment**	**Rep**	**Height AUGC**	**RCD AUGC**
Canthium	0	1	13162.25	1973.88
Canthium	0	2	12952.75	2018.43
Canthium	0	3	10674.00	2339.73
Canthium	1	1	12751.50	1861.44
Canthium	1	2	11157.25	2227.35
Canthium	1	3	8104.88	1868.68
Ficus	0	1	9406.13	2587.87
Ficus	0	2	6582.25	1810.08
Ficus	0	3	7092.13	2079.81
Ficus	1	1	8944.50	2345.43
Ficus	1	2	10602.50	2424.88
Ficus	1	3	12296.75	3017.46
Harpephyllum	0	1	12293.56	4140.82
Harpephyllum	0	2	11361.50	4278.33
Harpephyllum	0	3	13755.00	4629.02
Harpephyllum	1	1	9062.75	3260.54
Harpephyllum	1	2	12582.63	4128.48
Harpephyllum	1	3	10363.75	3830.50
Sclerocarya	0	1	9472.94	1773.43
Sclerocarya	0	2	6540.13	1172.35
Sclerocarya	0	3	6909.25	1314.42
Sclerocarya	1	1	8958.88	1609.39
Sclerocarya	1	2	9379.88	2250.49
Sclerocarya	1	3	11110.00	1959.51
Trichilia	0	1	7522.50	2216.62
Trichilia	0	2	9062.63	2386.83

Trichilia	0	3	9300.38	2086.99
Trichilia	1	1	8005.25	2632.37
Trichilia	1	2	7738.50	1959.87
Trichilia	1	3	9117.13	1791.18
Control-Eucalyptus	**0**		15571.80	1725.98
P- value			0.635	0.942
CV (%)			22.7	163.6

Appendix 5

Table 5.1: ANOVA of survival percentage of indigenous tree species cuttings grown in a rooting tunnel over 12 weeks.

Variate: Survival (%)	**S.S.**	**M.S.**	**V.R.**	**F Pr.**
Trees Species	141563.	35391.	17.88	<.001
Hormone	2458.	819.	0.41	0.743
Cutting type	1896.	948.	0.48	0.620
Trees Species x Hormone	11604.	967.	0.49	0.922
Trees Species x Cutting type	6438.	805.	0.41	0.917
Hormone x Cutting type	7854.	1309.	0.66	0.681
Trees Species x Hormone x Cutting type	25896.	1079.	0.55	0.964
SE	44.49			
CV (%)	104.2			

Table 5.2: ANOVA obtained from the growth of indigenous tree species cuttings in height grown in a rooting tunnel over 12 weeks.

Variate: Height	**S.S.**	**M.S.**	**V.R.**	**F Pr.**
Trees Species	4065.70	1016.43	10.63	<.001
Hormone	622.35	207.45	2.17	0.090
Cutting type	39524.53	19762.27	206.77	<.001
Trees Species x Hormone	4163.08	346.92	3.63	<.001
Trees Species x Cutting type	18572.36	2321.54	24.29	<.001
Hormone x Cutting type	3418.84	569.81	5.96	<.001
Trees Species x Hormone x Cutting type	9656.13	402.34	4.21	<.001
SE	9.776			
CV (%)	54.5			

Table 5.3: The effect of rooting hormones of five indigenous tree stem cuttings over a period of 21 weeks.

Species	Weeks After Planting (WAP)			
	0 WAP	**2 WAP**	**6 WAP**	**12 WAP**
F. sur	100a	85.44b	18.75b	8.33a
C. inerme	100a	89.59ab	41.67a	0b
S. birrea	100a	91.67a	8.33c	0b
T. emetics	100a	97.92a	2.08d	0b
H. caffrum	100a	0c	0ed	0b