EFFECT OF *Arbuscular mycorrhizal* FUNGI ON BANANA GROWTH DURING HARDENING PHASE AND FIELD PHASE IN NORTHERN TANZANIA

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ABSTRACT

Banana production contributes significantly to sustaining food security of the rural communities in Tanzania. However, yields in smallholder banana fields only represent 10% of the production potential due to recurrent drought stress, declining soil fertility, and increasing pests' pressure. Many plant species, including bananas, benefit from the presence of *Arbuscular mycorrhizal* fungi (AMF). Previous research on banana plants inoculated with AMF has shown encouraging outcomes. However, numerous studies have examined this under laboratory and screen house conditions. In light of this, field-based validation remains limited. In this context, two experiments were conducted in the northern highlands of Tanzania. The first experiment examined the effect of inoculating banana plantlets (*var*. Williams and Grand Naine) with three AMF strains (*Rhizophagus intraradices*, *Rhizophagus irregularis* and *Rhizophagus clarus*) on plant growth under nursery conditions. The results indicate that there were significant ($p<0.05$) and positive effects of AMF strains inoculation on banana plant growth parameters, with *Rhizophagus intraradices* recording the promising results compared to the control treatment. In the second experiment validated the effects of AMF strains with respect to growth and yield characteristics. The results show that *Rhizophagus intraradices* outperformed the other two strains. Overall, the results of this study indicate that AMF can be a useful addition to banana nursery management practices, resulting in improved growth and development during the critical weaning and hardening phases and, as well as improved field establishing success. These findings may have positive consequences in banana production in the long-term. The findings could also aid in optimizing the conventional banana production techniques by integrating AMF inoculants for enhanced banana production.

DECLARATION

I, Hellen Betson Mapunda, do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this dissertation is my original work and that it has neither been submitted nor being concurrently submitted for a degree award in any other institution.

Hellen Betson Mapunda Date

The above declaration is confirmed by:

Prof. Kelvin Mtei Date

Dr. Akida Meya Date

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance and approval by the Senate of the Nelson Mandela African Institution of Science and Technology a dissertation titled "*Impact of Arbuscular Mycorrhizal Fungi on Banana Growth during Hardening Phase and Field Phase"* submitted in partial fulfilment of the requirements for the award of the degree of Master of Science in Sustainable Agriculture of the Nelson Mandela African Institution of Science and Technology.

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Prof. Kelvin Mtei Date

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Dr. Akida Meya Date

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DEDICATION

I dedicate this work to my lovely family; my loving parents Mr. Betson Mapunda and Mr. Helga Mbelle, and beloved sisters Mr. Desderia Mapunda, Mr. Lidya Mapunda and my lovely brother Mr. Sadiki Mapunda. They have been my guiding light throughout this journey. Their love, unwavering support, encouragement, sacrifices, understanding during the challenging times, and endless belief in my abilities have inspired me to pursue excellence in all endeavors.

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LIST OF ABBREVIATIONS AND SYMBOLS

AMF	Arbuscular Mycorrhizal Fungi
ARUSHA DC	Arusha District Council
NM-AIST	Nelson Mandela African Institution of Science and Technology
UCL	Université Catholique de Louvain
MEDA	Mennonite Economic Development Associates
RCBD	Randomized Completely Block Design
ANOVA	Analysis of Variance
CRD	Completely Randomized Design
CO_2	Carbon dioxide
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
HAI DC	Hai District
Kg	Kilogram
T/ha	Tone per hectare

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

In developing countries, a significant portion of food is generated by smallholder farmers (Aguiar *et al.,* 2020). Despite their crucial role in food production, smallholder farmers face great challenges in terms of food security compared to the overall population (Tibesigwa *et al.,* 2015). Banana is estimated to feed about 30% of the population of Tanzania, implying that the crop contribute significantly in sustaining food and nutrition security (Net, 2018).

Earlier studies indicate that 85% of the harvested banana bunches is for family consumption, while the remaining 15% (mainly dessert bananas) is for local fresh market, thus contributing significantly in generating additional households' income (Jefwa *et al.,* 2012; Mahecha-Vásquez *et al.,* 2017; FAOSTAT, 2022). However, the average yield under smallholder fields is only 10% of the potential yield (Meya, 2021). The attainable low banana fruit yields in smallholder fields could be attributed to many factors, which includes insect pests, diseases, drought stress, lack of clean planting materials, labour shortage, farm fragmentation and declining soil fertility being the major constraints (Nkuba *et al.,* 2003; Jefwa *et al.,* 2012).

Like many other African countries, Tanzania is seeing a decline in banana production due to drought and other climate-related issue. Drought has severely impacted banana production in Tanzania, with studies documenting 30-50% yield losses in rain-fed systems during dry periods (Van Asten *et al.,* 2011). In key growing regions like Kagera, production has plummeted from 30-40 tons/ha to just 10-15 tons/ha due to water stress (Rugyerero, 2019). The economic consequences are stark, with smallholder farmers losing $200-$500 per hectare annually during droughts (FAO, 2020), while market disruptions like the 40% sales drop in Kilimanjaro (URT, 2018) worsen rural poverty.

Climate trends show growing vulnerability, with 70% of Tanzania's banana farms being rain-fed (World Bank, 2021) and a 20% rainfall decline in northern growing zones since 2000 (Drought, 2022). Drought also exacerbates disease outbreaks, increasing Fusarium wilt susceptibility 3-5 times (Mgenzi *et al.,* 2020) and Black Sigatoka infections by 50% (IITA, 2019). The human toll is evident in nutrition crises, such as Kagera's 25% reduction in daily calorie intake during the 2015-2016 drought (UNICEF, 2017), compounded by 60% price spikes in drought-affected markets (Tanzania Meteorological Agency, 2023). These quantified impacts underscore the urgent need for drought-resistant varieties, irrigation expansion, and climate adaptation strategies to safeguard Tanzania's banana-dependent livelihoods and food security, the bulk of Tanzania's bananas are grown by smallholder farmers who rely on rain-fed agriculture. As a result, they are quite concerned about the amount and distribution of rainfall.

Bananas, with their ever-present green canopy and relatively shallow root structure, are thought to need an abundant and constant supply of water in order to thrive (Adhikari *et al.,* 2015). For optimal banana production, a consistent weekly rainfall of 25 mm is ideal for healthy growth, while the total water requirement over the crop's life cycle ranges between 900 and 1200 mm (Ghosh *et al.*, 2018; Mustaffa & Kumar, 2012). Climate change is expected to disrupt rainfall patterns, increasing the frequency and severity of dry spells.

These prolonged droughts threaten banana yields by intensifying water stress a critical constraint since carbon absorption is essential for fruit production. Bananas require substantial amounts of CO_2 uptake to generate carbohydrates needed for fingers/fruits formation and development. However, stamatal closure during drought period reduces carbon assimilation, leading to significant yield losses due to small number and size of fingers (Van Asten *et al.*, 2011; Turner *et al.*, 2007).

A lack of readily available, high-quality planting material supplies is another obstacle to banana production. Getting suckers from already-established banana plants is a common practice among farmers, although it is labour intensive and yields insufficient seedlings. Additionally, traditional suckers may harbour soil-borne diseases such nematodes, banana corm weevils, and *Fusarium oxysporum*, fsp. *cubense*, the fungi that causes Fusarium wilt (Kasyoka, 2013). Although most disseminated agricultural technologies can contribute in alleviating poverty and food insecurity, debate persists over which innovations are most effective for small-scale adoption where only a minority of farmers initially embrace them (Kabunga *et al.,* 2014).

In underdeveloped nations, in particular, smallholder farmers who are poorly-resource endowed may be slow to adopt new, improved agricultural technologies that are advocated by many players. A lack of data and knowledge about farmers' needs, goals, and how the new technology works with their existing setup might be to blame (Kilwinger *et al.,* 2020). Although the tissue culture propagation technology has been available in Tanzania for almost a decade, most smallholder farmers have not reaped its benefits due to its high utilization cost. Hence, a straightforward and inexpensive method for producing banana seedlings in banana nurseries is required to enhance banana output in smallholder agricultural production systems.

Abiotic stresses have significantly constrained crop productivity, a challenge further exacerbated by climate change and unsustainable agricultural practices, including the over application of synthetic fertilizers and pesticides. Because of this, we must immediately begin researching and creating methods of banana management, which enhances crop yields and environmental health, such as the use of AMF. According to Begum *et al.* (2019) and Bowles *et al.* (2016), a large majority of terrestrial plants are home to symbiotic fungi known as the AMF.

Several studies have shown their impact on the development and survival of banana plantlets during the nursery period (Wahab *et al.*, 2023). Their functions have been previously shown in controlled environment studies to increase banana resistance to abiotic stresses like drought and aluminum toxicity, improve banana nutrition (especially phosphorus), biomass by penetrating soil beyond the root zone's nutrient depletion zone, and boost banana resistance to crop pests (Jeffries & Barea, 2012).

According to Wu (2017), AMF may get carbon and lipids from plants via symbiotic connections with their roots. In return, the host plant may benefit from the mineral nutrients released by the AMF. Several arbuscular mycorrhizal fungi (AMFs) have been tested on crops, *Rhizophagus* (formerly *Glomus*) remains the most widely used genus across various crops, including banana.

1.2 Statement of the Problem

Banana is a staple crop and cash earner for smallholder farmers in the humid highland areas of Tanzania. The increasing drought stress challenges caused by rising temperatures, altered precipitation patterns, poor agronomic practices, pests, diseases and the use of low yielding plant materials are causing a yield gap of nearly 90%, significantly disrupting farmers' income and affecting food security. In addition, the lack of clean planting materials prevents banana production from reaching its full potential (Jefwa *et al.,* 2012). The majority of Tanzanian smallholder farmers continue to rely entirely on suckers as their primary planting materials (Kilwinger *et al.,* 2020).

Tissue culture technology, particularly in commercial banana farming, is being adopted at a gradual pace among farmers (Wahome *et al.,* 2021). Moreover, the use of AMF inoculants is a recent development in tissue culture industries, leading to a limited availability of data on the status in Tanzania (Jefwa *et al.,* 2012). Furthermore, little is known about how AMF inoculant can improve banana plant performance in the field (Jefwa *et al.,* 2008). The commercialization of banana tissue culture has witnessed a significant increase in Tanzania as documented in Jefwa *et al.* (2012).

Tissue culture technology is progressively gaining popularity, particularly among farmers engaged in commercial banana farming in Tanzania (Kabunga *et al.,* 2014). This technological advancement plays a crucial role in addressing the previously mentioned constraints by facilitating the production of bulk clean planting material endowed with desirable features, including uniformity (Chamhuri Siwar *et al.,* 2009; Helliot *et al.,* 2002). When compared to plants grown from suckers, tissue culture plants are more photo-synthetically active because of their naturally high levels of juvenile vigor (Kasyoka, 2013).

In addition, compared to plants cultivated from traditional suckers, tissue culture plants have greater yields and may be easily transferred to farmers (Patel & Rath, 2018; Zou *et al.,* 2016). There is therefore a need for the adoption of tissue culture technology signifies a positive shift in the agricultural landscape in Tanzania, contributing to improved planting materials and overall farm productivity.

1.3 Rationale of the Study

Little is known about how the AMF inoculation can promote plant growth and improve banana plant performance in the field. Therefore, this study aims at gathering quantitative evidence on the benefits of AMF technology in enhance plant growth during nursery management phase and the overall yield in the field conditions.

1.4 Research Objectives

1.4.1 General Objective

To understand the impact of AMF inoculation on enhancing banana plant growth during nursery phase and the overall fruit yield in field conditions.

1.4.2 Specific Objectives

The research aimed to achieve the following specific objectives:

(i) To evaluate the performance of selected AMF strains in enhancing banana plantlets growth during the hardening phase in the nursery conditions.

(ii) To determine the effects of selected AMF strains on promoting banana plant growth and the overall crop yield under field conditions.

1.5 Research Questions

The study intended to answer the following questions:

(i) To what extent does AMF inoculation enhance banana growth during the nursery phase and field conditions linked to increase in survival rate, better vigor, and yield improvements?

(ii) How do selected AMF strains affect the fruit yield and quality of banana plants under field conditions?

1.6 Significance of the Study

The findings of this study will have broader implications for agricultural production, environmental sustainability, and economic outcomes in banana cultivation as well as help tissue culture laboratory firms reduce cost of micro-propagated banana plant during nursery management by shortening hardening duration, while generating stronger plantlets with AMF infection in the roots.

1.7 Delineation of the Study

The research was conducted in two phases. The first phase involved a nursery experiment to assess the influence of arbuscular mycorrhizal fungi (AMF) inoculation on the hardening stage of banana plantlets under screen house conditions. The second phase comprised a field experiment to evaluate the effect of selected AMF strains on banana growth promotion and total fruit yield.

CHAPTER TWO

LITERATURE REVIEW

2.1 Banana Production Trend

Banana is grown in tropical and subtropical regions with socio-economic importance worldwide. On average, banana is grown on a harvested land of 5.9 million hectares (ha) in 123 countries, with a total production volume of around 135.1 million tons of banana fingers each year (FAOSTAT, 2022). Globally, up to 2022, India was the biggest banana producer (34.5 million tons), followed by China (11.7 million tons) and Indonesia (9.2 million tons). In Africa, Nigeria was the largest banana producer (8.0 million tons), followed by Angola (4.5 million tons) and Tanzania (3.5 million tons) (FAOSTAT, 2022). According to FAOSTAT (2022), Tanzania grows bananas on 335 714 ha, with a total production of 3.5 million tons per year, making a total production of an approximately 2.5, 8.3 and 23.5 % of banana fruits in the world, Africa and East Africa, respectively.

There are two main areas in Tanzania where bananas are grown: primary and secondary. Northern Tanzania's Kilimanjaro, Arusha, and Tanga; Southern Tanzania's Mbeya; Eastern Tanzania's Coast and Morogoro; and the Zanzibar Islands make up the main producing regions (Nkuba *et al.,* 2003). Among the less important producing areas are Iringa, Kigoma, Mara, and Ruvuma. Bananas from the East Africa Highland, including Matooke, Uganda, Mchare, Kisukari, Mzuzu, Kimalindi, Ndizi Ng'ombe and Bokoboko, are the most widely grown banana kinds in all of these areas (Lucas, 2021).

The cooking banana, notably Matooke and Mchare, serves as a vital staple crop in Kagera, Kilimanjaro, Arusha, and Mbeya regions, being the favored food among most local communities (Marimo *et al.,* 2019). Bananas have been cultivated in these areas for an extensive period, thus becoming an integral component of the local culture and dietary habits (Mbwana & Rukazambuga, 1998). However, the average fruit yield in Tanzania is only 3.5 tons/ha compared with the potential of up to 70 tons/ha year (FAOSTAT, 2022). Increased land pressure due to rising human population densities, declining soil fertility and biotic stresses are reported to contribute to this yield decline (Gambart *et al.,* 2020).

2.2 Economic Importance of Banana Production

Bananas are a popular fruit and a nutritious snack since they are inexpensive, and full of fiber, carbs, and vitamins A, B6 and C (Phillips *et al.,* 2021). Bananas are an important and healthy food source in the East African Highland regions, even if they aren't very high in protein or fat (Hardaker & Lien, 2010). Many smallholder farmers in the area rely on bananas as a source of income, and the fruit is also an essential part of local cuisine (Nyombi, 2013). The bulk of Tanzania's bananas come from smallholder farmers, who typically have fields that are between half a hectare and one and a half acres in size (Kalyebara *et al.,* 2007; Ndunguru, 2009). Surplus bananas are sold in urban and certain rural village centres, although most of the bananas are cultivated for family use. Bananas are grown by an estimated 20-30% of Tanzania's population as a staple crop (Nkuba, 2007). Due to its year-round fruit production, the banana plant ensures food and economic stability for those living in banana-growing regions (Alemu, 2017).

Furthermore, for most smallholders engaged in banana farming, the fruit serves as a significant source of income for the majority of smallholders engaged in banana farming and the majority of smallholders engaged in banana farming, the fruit serves as a significant source of income (Meya, 2021). Bananas can undergo various processing methods to create a range of food products, including snacks, animal feed, industrial materials, handicrafts, and medicinal items (Edmeades *et al.,* 2007).

Different banana varieties are known for their varying levels of sweetness and flavor, making some ideal for desserts while others are better suited for cooking or roasting (Smale & Tushemereirwe, 2007). Bananas also have many other uses as well, including flour, beer, and Indigenous drinks like the Chagga people's traditional Mbege from Tanzania's northern highlands (Smale & Tushemereirwe, 2007). Besides being a direct source of food for people, bananas have many additional uses as well.

A number of components are utilized for therapeutic reasons, and the leftover fruits, peels, and other vegetative portions are often used as feed (Edmeades *et al.,* 2007). Also, women make things like hats, table mats, purses, envelopes, postcards, wall decorations using banana leaf midribs (Edmeades *et al.,* 2007). Mwanza, Shinyanga, Dodoma, and Dar es Salaam are among Tanzania's most important banana trade centers due to their high food demand, a result of high human population (Kibona, 2023).

2.3 Weather and Soil Requirements for Optimum Banana Production

According to Sharma *et al.* (2018), banana plants need a lot of water throughout their extended development cycle, which usually lasts about 10 to 12 months. There is consensus among experts that banana plants thrive when receives an annual rainfall of 1100–2650 mm, spread out throughout the year (Ghosh *et al.,* 2018; Mustaffa & Kumar, 2012). The ideal growth temperature range for the optimum banana plant growth is between 20 and 30°C (Sharma *et al.,* 2018). Conversely, banana plants thrive in deep, well-drained soils with high organic matter contents, and a pH range of 6.0 to 7.5 (Kasyoka, 2013).

According to Alvarez *et al.* (2001), banana output is greatly affected by soil water tension at various development stages, which results in a large decrease. According to Turner *et al.* (2007), banana plants block their stomata, limit transpiration, and lower photosynthetic rates even when soil moisture stress is modest. This is done to keep the leaves hydrated. According to Robinson and Saúco (1996) and Turner *et al.* (2007), the pace at which new leaves appear is seen as the most sensitive indication of drought stress in emerging banana tissues, which also include developing fruits and new leaves. Nevertheless, according to Vanhove *et al.* (2012), various banana genotypes may have vastly varied responses to drought stress.

2.4 Banana Propagation Methods

A banana plant may spread its seeds sexually and its suckers asexually (Singh *et al.,* 2011). Wild banana species often reproduce by seed, with varying degrees of germinability, dormancy, and seed set (Kasyoka, 2013). Except for a small number of diploid parthenocarpic AA and AB bananas, all commercially grown bananas are triploid and fertile (Kasyoka, 2013). There are two ways to get planting material for bananas: tissue culture and traditional production.

2.4.1 Conventional Banana Propagation Method

The conventional method of propagating bananas using suckers is a very slow process that results in low multiplication of planting material as a banana plant only produces 5-20 suckers in its lifetime (Wahome *et al.,* 2021). In light of this, total reliance on the conventional banana propagation method limits the accessible amounts of planting material. As a result, 60% of banana farmers in African countries, including Tanzania, obtain suckers from the existing fields (Kasyoka, 2013). On the other hand, the spread of insect’s pests and diseases when suckers from the producing fields are used as planting material is a major disadvantage of the conventional method of banana propagation (Patel & Rath, 2018).

2.4.2 Modern Banana Propagation Method

The use of tissue culture technology has opened the door to the prospect of mass production of healthy banana seedlings (Okinyi, 2012). Producing bananas using tissue culture technology is very efficient because it enables a rapid and massive turnover of sanitary planting materials in a constrained amount of time and area (Wahome *et al.,* 2021). The banana industry in Tanzania and other African countries stands to benefit greatly from tissue culture technologies. The lengthy time that seedlings spend in the nursery during the weaning and hardening periods causes high utilization costs, which in turn reduces the adoption rates of tissue culture, despite its critical importance in improving agricultural productivity and attaining sustainability in banana production (Cardoso & Kuyper, 2006).

2.4.3 Utilization Costs of Tissue Culture Banana Planting Materials

In East Africa, the adoption of tissue culture banana planting materials remains relatively low due to its restrictive high price caused by the high cost of production (Muyanga, 2009; Lule *et al.,* 2011). Production of tissue culture plantlets requires a high investment cost as compared to the conventional propagation methods (Muhammad *et al.,* 2004; Lule *et al.,* 2011; Xu *et al.,* 2011). This costs disparity has been a major limiting factor in adoption of tissue culture technology. For instance, Muyanga (2009) observed that in Kenya, the high production expenses of tissue- cultured planting materials have contributed to their limited use, as farmers prefer more affordable conventional alternatives.

Consequently, many private companies hesitate to invest on tissue culture commercial laboratories. Despite of the above-mentioned constraints, in vitro multiplication of banana plantlets is an excellent alternative to the use of suckers because it provides clean planting materials that are free from pest and diseases (Abdelmajeed & Aboul- Nasr, 2013).

2.4.4 Integrating Tissue Culture and Environmental-Friendly Technology for Sustainable Banana Production

Overuse of pesticides and fertilizers, along with other agricultural malpractices, has further reduced crop output and worsened environmental damage caused by abiotic stresses (Madalla *et al.*, 2022; Ryan & Graham, 2018). Because of this, improving land productivity via the use of AMF is one ecologically friendly banana management strategy that has to be developed immediately (Begum *et al.,* 2019; Bowles *et al.,* 2016). To promote sustainable banana production, there is a need to integrate tissue-cultured planting materials with AMF inoculation as this approach not only enhances plant performance but also offers environmental benefits (Jefwa *et al.,* 2012). By enhancing soil structure, boosting plant tolerance to biotic and abiotic stressors, and facilitating improved nutrient absorption, integration of AMF technology with these planting materials further promotes plant health (Jeffries & Barea, 2012).

2.5 Origin of Arbuscular Mycorrhizal Fungi

Arbuscular mycorrhizal fungi are naturally occurring in soil and may be used as bio-stimulants and biological control agents (Rouphael *et al.,* 2015). According to Begum *et al.* (2019), the majority of AMF species are Glomeromycotina, a family of Mucoromycota. A further benefit of AMF-mediated growth promotion is that it enhances nutrient and water absorption from adjacent soil, while also protecting plants from fungal infections (Bowles *et al.,* 2016). The process is accomplished by enhancing the photosynthetic rate and other gas exchange-related factors through a series of complex communication events between the plant and the fungus (Declerck *et al.,* 2002; Jefwa *et al.,* 2010; Birhane *et al.,* 2012; Begun *et al.,* 2019).

According to Jeffries and Barea (2012), there is a common belief that inoculating host plants with AMF makes them more resistant to heat, salt, drought, metals and high temperatures. In addition to preventing the downregulation of important metabolic pathways, the AMF may help host plants increase tolerance mechanisms (Oye *et al.,* 2016). As natural root symbionts, AMF boosts host plant development and yield in both stress-free and stressful environments by supplying vital plant nutrients (Abdel-Salam *et al.,* 2018).

Plants may be better able to withstand environmental changes if AMF is used as a bio-fertilizer. According to Rouphael *et al.* (2015), AMFs may be found in the rhizosphere in the form of spores and hyphae, and the roots as vesicles and arbuscules. When AMF establishes a hyphal network with plant roots, it allows roots to access a wider soil surface area, which increases the availability and transport of critical nutrients. This, in turn, enhances plant nutrition (Rouphael *et al.,* 2015). Soil microfungi (AMF) improve soil quality by influencing soil structure and texture, whereas hyphae may speed up organic matter decomposition and contribute to soil health (Thirkell *et al.*, 2017; Zou *et al.*, 2016; Paterson *et al.*, 2016). Begum *et al.* (2019) found that mycorrhizal fungus may alter atmospheric CO_2 fixation by host plants by influencing the "sink effect" and the migration of photo-assimilates from aerial sections to the roots.

2.6 Characteristics of AMF Symbiosis

The AMF-banana symbiosis has mostly targeted a small number of AM fungus species, most notably the alien Glomus (now known as Rhizophagus), in order to adapt banana cultivars in tissue culture (Jefwa *et al.,* 2010). In nature, AMF often establishes symbiotic connections with plant roots, which may benefit the host plant in several ways. One example of a mutualistic connection is the symbiotic link between AMF and host plants (Bi *et al.*, 2019). This relationship has the potential to govern the development and growth of the host plants (Begum *et al.,* 2019).

By working together to enhance soil properties, these beneficial organisms boost host plants' resistance to biotic and abiotic challenges, allowing them to thrive in both ideal and challenging environments (Plassard & Dell, 2010). The use of AMF to promote plant development in different ecological contexts is shown in Fig. 1.

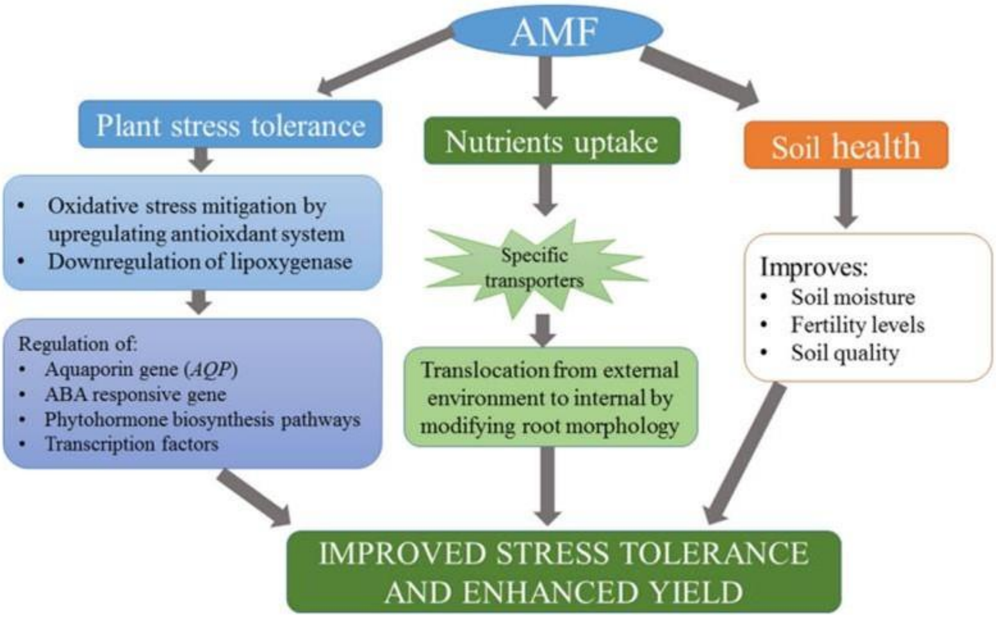

Figure 1: Mycorrhizal function regulating various process in ecosystem and plant growth under abiotic stress condition (Begum *et al.,* 2019)

Jefwa *et al.* (2008) documented that AMF inoculation increased plant growth parameters in a Jiffy pots. TSBF (2007) found that AMF inoculation improved banana plantlets' phosphorous absorption under greenhouse conditions. Several theories have been put out to account for the phenomenon, such as enhanced stomatal regulation, increased root hydraulic conductivity, better soil particle contact due to hyphae binding, and the ability to draw water from smaller pores (Bowles *et al.,* 2016; Rouphael *et al.,* 2015).

There is evidence that AMF colonization of plant roots may reduce damage caused by soil-borne pests such as nematodes (Elsen *et al.,* 2004; Gowen *et al.,* 2005; Jefwa *et al.,* 2008). Oye *et al.* (2016) suggested that studying bananas' resistance to insect pests and diseases could be possible by looking at their root systems and shoots, as well as the amount of silicon they accumulated before colonization (Anda *et al.,* 2016; Gbongue *et al.,* 2019). In symbiotic relationships, AMF helps host plants grow faster and stronger even when faced with challenging growth circumstances. So, AMFs are important for long-term crop development because e they are essential endosymbioses that boost plant production and ecosystem function (Begum *et al.,* 2019; Bowles *et al.,* 2016).

2.7 Trend in AMF-Banana Research in Africa

In Africa, a few research studies concerning AMF in banana production and the management of crop pests and other abiotic stresses have been conducted (Begum *et al.,* 2019; Diagne *et al.,* 2020). Current banana soil fertility, pest, and disease management approaches mostly depend on cultural techniques such as crop sanitary and are mostly dependent on cultural techniques such as crop sanitary and the utilization of organic fertilizer resources (Baijukya & Steenhijsen, 1999; Jefwa *et al.,* 2012). The AMF has been proven to have tremendous promise in helping to solve soil fertility, pests, and disease restrictions, as they provide a protective effect on banana micro-propagated plantlets (Jefwa *et al.,* 2012; Rouphael *et al.,* 2015; Begun *et al.,* 2019). Begum *et al.* (2019) have reported on AMF research in African banana systems investigations led by several institutions.

The following findings were derived from the research: First, the AMF species, soil type, and banana cultivars all play a role in the banana's reaction to AMF; second, the amount of available Phosphorus in the soil seems to affect the rate of AMF colonization; however, high colonization has been noted at sites with a high available Phosphorus concentration; and third, AMF can reduce the pressure of black leaf streak disease and nematode populations (Bowles *et al.*, 2016). These findings underscore the context- dependent nature of AMF interactions with banana plants, highlighting their potential as sustainable tool for improving banana plant nutrition and resilience under varying soil and environmental conditions.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site Description

The field experiments were established in two sites. The first field experiment was established at Mbosho village, Masama Kati ward (4.1337° S, 37.8088° E) in the Kilimanjaro region. The average temperature in this area ranges between 15°C and 32°C in cold and hot months, respectively. The annual rainfall in the region is around 1600 mm. Marurani village, located in the Nduruma ward at 3.3869° S and 36.6830° E in the Arusha district, was the second site of the field experiment. The coldest months are June and July, while the warmest are January and February, with a mean temperature ranging from 13 to 34°C.

The average annual precipitation is 800 mm, which indicates the average annual precipitation is 800 mm, indicating a bimodal rainfall regime (Ojiewo *et al.,* 2013). An attitude gradient ranging from 1240 to 4068 m above sea level (m a.s.l.) was the site of the experimental fields. The length of time it rains varies in each location. The brief downpour begins in October, peaks in December, and then disappears in January. March is the beginning of the lengthy rains, which last until June.

The study sites were purposively selected to represent major banana growing areas in the northern highlands zone. In addition, these sites are currently targeted for the introduction of rapid multiplication technologies and new business distribution models as per RAPID Banana project planning.

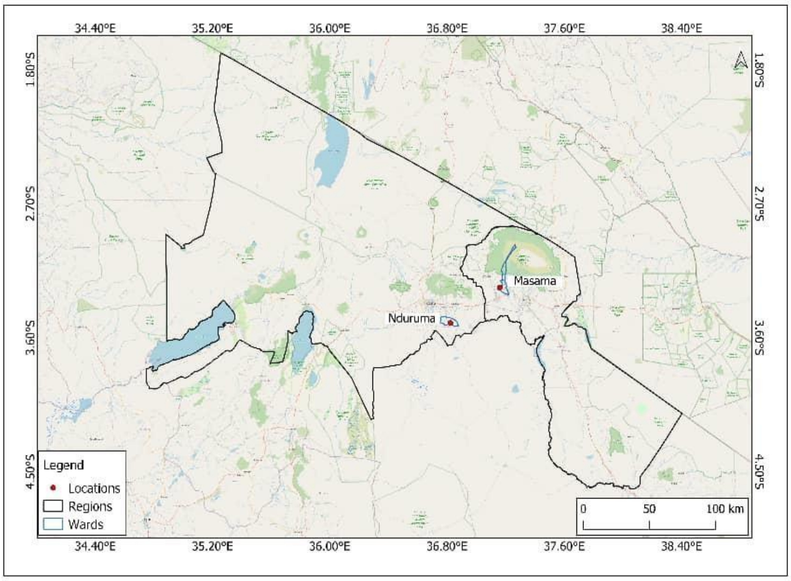

Figure 2: Map of the study sites

3.2 Methods per Objective Wise

3.2.1 Material and Methods: To Evaluate the Performance of Selected AMF Strains in Enhancing Banana Plantlet Growth During the Weaning and Hardening Phase in Nursery Conditions

Three AMF strains (*Rhizophagus irregularis*, *Rhizophagus intraradices* and *Rhizophagus clarus*) were used to evaluate their contribution in promoting banana plantlet growth during the weaning and hardening phase in nursery conditions. In vitro banana plantlets var. Grand Naine and Williams were used as test varieties. The AMF inoculum was provided in the form of colonized root pieces supplied by the laboratory of mycology of Université Catholique de Louvain (UCL). The AMF inoculum, consisting of a few milligrams of colonized root pieces was placed in the planting hole in the middle of the pots (Jiffy and polyethylene tubes; the latter being the traditional/regular pot). The roots of each banana plantlet were trimmed then, plantlets were placed in the pots to allow roots to grow through the inoculum.

The inoculated banana plantlets were grown in the humidity chamber for two weeks thereafter were removed and allowed to complete the weaning phase for two weeks under screen house conditions. Then, banana plantlets (both inoculated and uninoculated) were transferred to a shade house to complete the hardening stage until they attained four fully open leaves. A factorial experiment with three factors (4 × 2 × 2) arranged in a completely randomized design was used. The first experimental factor was AMF strains with four levels (AMF strain A - *Rhizophagus irregularis*, AMF strain B - *Rhizophagus intraradices*, AMF strain C - *Rhizophagus clarus,* and a control) as the first factor. The second factor was banana cultivars, which included Grand Naine and Williams as a sub-factor. The third experimental factor was planting soil (jiffy containing cocopeat and regular polyethylene tubes containing forest soil). Data collected in this objective includes plant height, leaf surface area, number of leaves (at 4, 6, 8, 10 weeks interval), and days to four fully developed leaves.

3.2.2 Materials and Methods: The Goal of this Experiment is to Find out How Different AMF Strains Affect Banana Plant Development and Fruit Output In the Field

Banana plantlets set (a) inoculated with three selected AMF strains, and (b) uninoculated from the nursery experiment were transplanted to the experimental fields when they attained four fully open leaves stage. The banana plantlets were planted following a RCBD arranged in a split plot experiment with AMF being the main plot factor and banana varieties the sub plot factors with three replicates. Planting of banana plantlet was done during rainy season. Figure 2 shows the field layout and the experimental treatments allocation. The planting spacing was 3 m by 3 m, equivalent to 1111 plants per hectare (ha^{-1}). The planting hole had the following dimensions: 0.8 m width and 0.6 m depth. The planting holes were individually amended with twenty (20) kg of an organic fertilizer that had been stockpiled. We used a non-destructive approach to gather data on plant development characteristics (pseudo stem height, leaf count, leaf breadth and length) and yield parameters (hand count, finger count, bunch weight). We tracked the plant's growth characteristics monthly all the way up to blooming.

FIELD EXPERIMENTAL LAYOUT

REPLICATION 1	T1	T6	T4	T7	T5	T3	T8	T2
REPLICATION 2	T8	T2	T7	T3	T6	T4	T1	T5
REPLICATION 3	T5	T1	T8	T4	T2	T6	T3	T7

Figure 3: **Field experimental layout. T1 = Williams + AMF strain A, T2 = Williams**

+AMF strain B, T3 = Williams +AMF strain C, T4 = Williams +Control, T5 = Grand Naine +AMF strain A, T6 = Grand Naine +AMF strain B, T7 = Grand Naine +AMF strain C, T8 = Grand Naine

3.3 Data Analysis

Analysis of Variance (ANOVA) was used to determine mean differences between strains while Tukey's test was employed for means comparisons of the tested strains at ($P \leq 0.05$). T- test was used to determine mean difference between the varieties, media and sites. Data was presented using tables.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Effects of Varieties, Growth Media and AMF Strains on Banana Plantlets Height and Leaf Surface Area after Planting in the Nursery

Table 1, 2 and 3 present data on the effects of selected banana varieties, growth media and AMF strain on plant height and leaf surface area at 8 weeks after planting in the nursery experiment. The results indicate that there were significant ($p < 0.05$) and positive effects of AMF strains inoculation on banana plant height at 8 weeks after the establishment of the nursery experiment. The AMF strain B recorded the highest value (8.74 cm) for plant height while the control recorded the lowest value (8.25 cm).

Banana varieties exhibited a highly significant ($p < 0.001$) variation in plant height at 8 weeks after establishing the nursery experiment, with Williams recording the highest value (9.08) for plant height compared with Grand Naine which recorded the value of 8.07 cm. Also, the results demonstrated a highly significant ($p < 0.001$) difference between growth media at 8 weeks after establishing nursery experiment. Plants grown in polyethylene pots containing forest soil were taller (10.16 cm) than those grown in Jiffy pots (6.99 cm) containing cocopeat as growth media.

The results further indicated that AMF strains inoculation had no significant ($p < 0.05$) effects on the leaf surface area of the tested banana varieties eight weeks after planting. Similarly, the results of this study showed that the tested banana varieties did not differ significantly ($p<0.05$) in terms of leaf surface area 8 weeks after planting the nursery experiment. On the contrary, the results indicated a highly significant difference ($p < 0.001$) between growth media used in the nursery experiment, with plants grown in the forest soil in polyethylene pots recording the highest value (110.70 cm^2) for leaf surface compared with those in Jiffy pots containing cocopeat (47.60 cm^2).

Table 1: Effects of AMF strains on plantlet height and leaf surface after establishment of the nursery experiment

AMF strains	Plant height (cm)	Leaf surface area (cm2)
A	8.617ab	78.89a
B	8.747b	80.99a
C	8.685ab	80.42a
Control (No strain)	8.251a	78.35a
Grand mean	8.575	79.27
CV %	4.8	5.9
P-value	0.042	0.787

Values in the same column, followed by the same letter(s) do not differ significantly ($p \leq 0.05$) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

Table 2: Effects of banana varieties on plantlet height and leaf surface after establishment of the nursery experiment

Banana Varieties	Plant height (cm)	Leaf surface area (cm^2)
Williams	9.081b	79.4a
Grand Naine	8.069a	79a
Grand mean	8.575	79.27
CV %	4.8	5.9
P-value	<.001	0.839

Values in the same column, followed by the same letter(s) do not differ significantly ($p \leq 0.05$) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

Table 3: Effects of growth media on plantlet height and leaf surface after establishment of the nursery experiment

Growth media	Plant height (cm)	Leaf surface area (cm^2)
Forest Soil in Polyethylene pots	10.159b	110.7b
Coco peat in Jiffy pots	6.991a	47.6a
Grand mean	8.575	79.27
CV %	4.8	5.9
P-value	<.001	<.001

Values in the same column, followed by the same letter(s) do not differ significantly ($p \leq 0.05$) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

4.1.2 Interaction Effects of Varieties, Growth Media and AMF Strains on Banana Plantlets Height and Leaf Surface Area after Establishment of the Nursery Experiment

Tables 4, 5, 6 and 7 show the results on the interaction effects of varieties, growth media and AMF strains on banana plantlets height and leaf surface area 8 weeks after establishing the nursery experiment. The interaction between banana varieties and AMF strains significantly ($p < 0.05$) affected both banana plantlets height and leaf surface area at 8 weeks after planting in the nursery experiment. The interaction between Williams and AMF strain B recorded the highest value (9.211 cm) for plant height while the lowest value (7.29 cm) was observed in the interaction between Grand Naine and control. Also, the interaction between Grand Naine and AMF strain B recorded the largest leaf surface area (84.01 cm^2) while the interaction between Grand Naine and AMF strain C showed the smallest leaf surface area (73.37 cm^2).

In addition, the results showed that the interaction between banana varieties and growth media significantly ($p < 0.05$) affected both plant height and leaf surface area at 8 weeks after establishing the nursery experiment. The interaction between Williams and forest soil in polyethylene pots recorded the largest values for banana plantlets' height and leaf surface area (10.469 and 105.13 cm^2, respectively). The interaction between Grand Naine and cocopeat in Jiffy pots recorded the smallest values for banana plantlets' height (7.292 and 40.40 cm, respectively).

The interaction between strain and media did not significantly ($p < 0.05$) affect both plant height and leaf area eight weeks after planting. On the contrary, the interaction among banana varieties, AMF strains, and growth media significantly ($p < 0.05$) affected both plant height and leaf surface area at 8 weeks after establishing the nursery experiment. The interaction among Grand Naine × AMF strain B × forest soil in polyethylene pots resulted in the largest values for banana plantlets' height and leaf surface area (12.028 and 117.10 cm^2, respectively) while the interaction between Williams × Strain A × Jiffy showed the lowest plant height (6.30 cm) and leaf area (37.39 cm^2).

Table 4: The interaction effect of banana varieties and AMF strain on plantlet height and leaf surface area after Establishment of the Nursery Experiment

Banana Varieties	AMF strains	Plant height (cm)	Leaf surface area (cm^2)
Williams	A	9.081cd	76.51a
	B	9.211d	83.48a
	C	9.036cd	77.97a
	Control (No strain)	8.994cd	79.55a
Grand Naine	A	8.153b	80.19a
	B	8.500bcd	84.01a
	C	8.333bc	73.37a
	Control (No strain)	7.292a	78.24a
Grand mean		8.575	79.2
CV %		4.8	5.9
P-value (Banana varieties)		<.001	0.939
P-value (AMF strains)		0.042	0.787
P-value (Variety x AMF strains)		*<.001*	*0.034*

Values in the same column, followed by the same letter(s) do not differ significantly (P<0.05) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus*.

Table 5: The interaction effect of banana varieties and growth media on plantlets height and leaf surface area after establishment of the nursery experiment

Banana variety	Growth media	Plantlet height (cm)	Leaf surface area (cm^2)
Williams	Forest soil in polyethylene pots	11.471d	118.35d
	Cocopeat in Jiffy pots	6.690a	40.40a
Grand Naine	Forest soil in polyethylene pots	8.847c	103.09c
	Cocopeat in Jiffy pots	7.292b	54.82b
Grand mean		8.575	79.2
CV %		4.8	5.9
P value		*<.001*	*<.001*

Values in the same column, followed by the same letter(s) do not differ significantly (P<0.05) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

Table 6: The interaction effect of AMF strain and growth media on banana plantlet height and leaf surface area after establishment of the nursery experiment

AMF strains	Growth media	Plant height(cm)	Leaf surface area (cm^2)
A	Forest soil	9.639b	105.13b
	Cocopeat	6.764a	51.57a
B	Forest soil	10.469c	114.44b
	Cocopeat	6.864a	46.53a
C	Forest soil	10.250bc	110.31b
	Cocopeat	7.119a	47.55a
Control (No strain)	Forest soil	10.278bc	113b
	Cocopeat	7.217a	44.79a
Grand mean		8.575	79.27
CV %		4.8	5.9
P-value (AMF strains)		0.042	0787
P-value (Growth media)		<.001	<.001
P-value (AMF strains xGrowth media)		0.096	0.059

Values in the same column, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) according to Tukey's honestly significance test. A = *Rhizophagus irregularis*, B = *Rhizophagus intraradices*, C = *Rhizophagus clarus*.

Table 7: The interaction effect of banana varieties, AMF strains and growth media on plantlets height and leaf surface area after establishment of the nursery experiment

Banana Variety	AMF strains	Growth media	Plant height (cm)	Leaf surface area (cm^2)
Williams	A	Forest soil	6.394a	111.69def
		Cocopeat	6.306a	37.39a
	B	Forest soil	11.856d	129.57f
		Cocopeat	9.083b	41.34a
	C	Forest soil	11.111d	111.77def
		Cocopeat	6.961a	44.18ab
	Control (No strain)	Forest soil	10.889cd	120.39ef
		Cocopeat	7.100a	38.70a
Grand Naine	A	Forest soil	9.083b	98.58cd
		Cocopeat	7.222a	61.80b
	B	Forest soil	12.028d	117.10def
		Cocopeat	7.333a	55.68b
	C	Forest soil	9.389b	91.06c
		Cocopeat	7.278a	50.92ab
	Control (No strain)	Forest soil	9.667bc	105.60cde
		Cocopeat	7.333a	50.88ab
	Grand mean		*8.575*	*79.2*
	CV %		*4.8*	*5.9*
	P-value (Banana variety)		<.001	0.939
	P-value (AMF strains)		0.042	0.787
	p-value (Growth Media)		<.001	<.001
	P-value(variety x AMF strains)		*<.001*	*0.034*
	P-value (Variety x growth media)		<.001	<.001
	P-value (AMF x Growth media)		0.096	0.059
	P-value (Variety x AMF starins x Growth media)		<.001	<.001

Values in the same column, followed by the same letter(s) do not differ significantly (P<0.05) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

4.1.3 Effects of Varieties, Growth Media and AMF Strains on Number of Days to Four Leaves Stage of Banana Plantlets in the Nursery Experiment

The results on the effects of varieties, growth media and AMF strains on the number of days to four leaves stage of banana plantlets in the nursery experiment are shown in Table 6. The tested banana varieties showed highly significant difference ($p<0.001$) in number of days to reach four leaves stage whereby Williams took shorter duration (46 days) than Grand Naine (55 days). Likewise, growth media showed highly significant influence ($p<0.001$) in days to four leaves stage whereby banana plantlets grown in forest soil in polyethylene pots took short period (50 days) while those grown under cocopeat in Jiffy pots took up to 54 days. In addition, the results further indicated a significant ($p<0.05$) effect of AMF strains inoculation on the number of days to four leaves stage, with AMF strain B inoculant recording the shortest duration (48 days) compared to the control treatment (57 days).

Table 8: Effects of AMF strains inoculation on the number of days to 4 leaves stage of banana plantlets in the nursery experiment

AMF strains	Days to 4 leaves
A	50.85ab
B	48.67a
C	52.25b
Control (No strain)	57.94c
Grand mean	52.43
CV %	4.8
P-value	<.001

Values in the same column, followed by the same letter(s) do not differ significantly ($p<0.05$) according to Tukey's honestly significance test. A = *Rhizophagus irregularis* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

Table 9: Effects of varieties on the number of days to 4 leaves stage of banana plantlets in the nursery experiment

Banana varieties	Days to 4 leaves
Williams	46.76a
Grand naine	55.09b
Grand mean	52.43
CV %	4.8
P-value	<.001

Values in the same column, followed by the same letter(s) do not differ significantly ($p<0.05$) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

Table 10: Effects of growth media inoculation on the number of days to 4 leaves stage of banana plantlets in the nursery experiment

Growth media	Days to 4 leaves
Forest soil in polyethylene pots	50.2a
Cocopeat in Jiffy pots	54.65b
Grand mean	52.43
CV %	4.8
P-value	<.001

Values in the same column, followed by the same letter(s) do not differ significantly ($p<0.05$) according to Tukey's honestly significance test. A = *Rhizophagus irregularis* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

4.1.4 Interaction Effects of Varieties, Growth Media and AMF Strains on the Number of Days to 4 Leaves Stage of Banana Plantlets in the Nursery Experiment

Tables 11, 12, 13 and 14 show the results on the interaction effects of varieties, growth media and AMF strains on the number of days to four leaves stage of banana plantlets in the nursery experiment. The interaction between varieties and AMF strains had a significant (*p*<0.05) influence on the number of days to four leaves stage of banana plantlets. The interaction between Williams and AMF strain B recorded the shortest duration (43 days), while that of Grand Naine and control recorded the longest duration (58 days). Similarly, the interaction between variety and growth media significantly (*p*<0.05) affected the number of days to four leaves stage of banana plantlets. The interaction between Williams and forest soil in polyethylene pots documented the lowest value for the number of days (46 days) to four leaves stage of banana plantlets while Grand Naine with cocopeat in Jiffy pots had the highest value of up to 56 days.

In addition, the interaction between AMF strains and growth media significantly (p<0.05) affected the number of days to four leaves stage of banana plantlets. The interaction between control × cocopeat in Jiffy pots showed the largest number of days (58 days) to four leaves stage of banana plantlets, while that of strain B and forest soil in polyethylene pots showed the smallest number of days (47 days). The interaction between varieties, AMF strains and growth media significantly (p<0.05) affected number of days to four leaves stage of banana plantlets.

Table 11: Interaction effects of banana variety and AMF strains on the number of days to 4 leaves stage of banana plantlets in the nursery experiment

Banana Variety	AMF strains	Days to 4 leaves stage
Williams	A	48.61b
	B	43.08a
	C	49.81bc
	Control (No strain)	57.56ef
Grand Naine	A	53.08cd
	B	54.25de
	C	54.69ded
	Control (No strain)	58.33f
Grand mean		*52.43*
CV %		*0.9*
P-value (Banana variety)		<.001
P-value (AMF strains)		<.001
P-value (Banana varieties x AMF strains)		<.001

Values in the same column, followed by the same letter(s) do not differ significantly (p<0.05) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

Table 12: Interaction effects of banana varieties and growth media on the number of days to 4 leaves stage of banana plantlets in the nursery experiment

Banana Variety	Growth media	Days to 4 leaves stage
Williams	Forest soil in polyethylene pots	46.64a
	Cocopeat in Jiffy pots	52.89b
Grand Naine	Forest soil polyethylene pots	53.76b
	Cocopeat in Jiffy pots	56.42c
Grand Mean		52.43
CV %		0.9
P-value (Banana variety)		<.001
P-value (Growth media)		<.001
P-value(Banana varieties x Growth media)		0.005

Values in the same column, followed by the same letter(s) do not differ significantly (p<0.05) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

Table 13: Interaction effects of AMF strain and growth media on the number of days to 4 leaves stage of banana plantlets in the nursery experiment

AMF strains	Growth media	Days to 4 leaves stage
A	Forest soil in polyethylene pots	47.83a
	Cocopeat in Jiffy pots	53.86b
B	Forest soil polyethylene pots	47.56a
	Cocopeat in Jiffy pots	49.78a
C	Forest soil polyethylene pots	48.25a
	Cocopeat in Jiffy pots	49.78a
Control (No strain)	Forest soil polyethylene pots	57.17bc
	Cocopeat in Jiffy pots	58.72c
Grand mean		*52.43*
CV %		*0.9*
P-value (AMF strain)		<.001
P-value (Growth media)		<.001
p-value (AMF strains x Growth Media)		<.001

Values in the same column, followed by the same letter(s) do not differ significantly (p<0.05) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

Table 14: Interaction effects of banana variety, strain and media on the number of days to 4 leaves stage of banana plantlets in the nursery experiment

Banana variety	AMF strains	Growth media	Days to 4 leaves stage
Williams	A	Forest soil in polyethylene pots	44.33a
		Cocopeat in Jiffy pots	52.89b
	B	Forest soil polyethylene pots	43a
		Cocopeat in Jiffy pots	43.17
	C	Forest soil polyethylene pots	44.39
		Cocopeat in Jiffy pots	55.22bc
	Control (No strain)	Forest soil polyethylene pots	54.83bc
		Cocopeat in Jiffy pots	60.28c
Grand Naine	A	Forest soil in polyethylene pots	51.33a
		Cocopeat in Jiffy pots	54.83bc
	B	Forest soil polyethylene pots	52.11b
		Cocopeat in Jiffy pots	56.39bc
	C	Forest soil polyethylene pots	52.11b
		Cocopeat in Jiffy pots	57.28bc
	Control (No strain)	Forest soil polyethylene pots	59.50c
		Cocopeat in Jiffy pots	57.17bc
Grand mean			*52.43*
CV %			*0.9*
P-value (Banana variety)			<.001
P-value (AMF strains)			<.001
p-value (Growth Media)			<.001
P-value(variety and AMF strains)			<.001
P-value (Variety and growth media)			0.005
P-value (AMF and Growth media)			<.001
P-value (Variety x AMF starins x Growth media)			0.006

Values in the same column, followed by the same letter(s) do not differ significantly ($p<0.05$) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

4.1.5 Effects of Study Sites, Banana Varieties and AMF Strains on Plant Growth Parameters after Field Transplanting

Table 15, 16 and 17 shows the effects of the study sites, banana varieties and AMF strain on plant height, number of leaves and leaf surface area in the field experiment. The results showed that study sites significantly ($p < 0.05$) affected the investigated growth parameters (except, plant height). The Arusha Dc site recorded the highest values for the number of leaves and leaf surface area (14 and 4827.41cm^2, respectively) compared with the Hai site

(12 and 3355.10 cm^2, respectively).

In addition, the results showed that the study sites did not affect significantly (*p*<0.05) the investigated growth parameters of the tested banana varieties. On the contrary, the results indicated that study sites had a significant (*P*<0.05) effect on the performance of selected AMF strains as reflected on the investigated growth parameters (except, leaf surface area). The tested strains did not significantly (*P*<0.05) affect leaf surface area while significantly (p< 0.05) affected the number of leaves and plant height. Strain B showed the highest number of leaves (4451 and 13.43, respectively) while strain B showed the highest plant height (109.1 cm).

Table 15: Effects of the study sites on banana plant growth parameters after of the field transplanting

Study sites	Leaf surface area (cm^2)	Number of leaves	Plant height (cm)
Nduruma	4827.41b	14.13b	101.15a
Masama kati	3355.10a	11.98a	102.20a
Grand Mean	4102	13.06	101.7
CV %	11	0.8	1.6
P-value	*<.001*	*<.001*	*0.725*

Values in the same column, followed by the same letter(s) do not differ significantly (*p*<0.05) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

Table 16: Effects of varieties on banana plant growth parameters after of the field transplanting

Banana varieties	Leaf surface area (cm^2)	Number of leaves	Plant height (cm)
Williams	4089.86a	13.29a	101.93a
Grand Naine	4090.38a	12.80a	101.51a
Grand Mean	4102	13.06	101.7a
CV %	11	0.8	1.6
p - value	*0.987*	*0.195*	*0.918*

Values in the same column, followed by the same letter(s) do not differ significantly (p<0.05) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

Table 17: Effects of AMF strains on banana plant growth parameters after of the field transplanting

AMF strains	Leaf surface area (cm2)	Number of leaves	Plant height (cm)
A	4067ab	13.36a	103.6b
B	4451b	13.43a	109.1b
C	4244ab	13.42a	89.4a
Control(no strain)	3646a	12.04a	104.9b
Grand Mean	4102	13.06	101.7
CV %	11	0.8	1.6
P-value	0.061	0.026	<001

Values in the same column, followed by the same letter(s) do not differ significantly (p<0.05) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

4.1.6 The Interaction Effect of Site, Variety and AMF Strain on Banana Plant Growth Parameters following field establishment

Table 18, 19, 20 and 21 shows the results on the interaction effect of site, variety and AMF strain on leaf area, number of leaves, and plants height 28 weeks after establishment of the field experiment. The interaction between site × variety significantly (p<0.05) affected only the number of leaves while did not affect leaf area and plant height. The interaction between Hai × Williams showed the highest plant height (144.8 cm), the interaction between Arusha Dc × Grand Naine showed the highest number of leaves (9.542) and the interaction between Arusha Dc × Grand Naine showed the highest leaf area (4890 cm^2).

The interaction between site × Strain significantly (p<0.05) affected plant height and leaf area while did not affect number of leaves. The interaction between Arusha Dc × Strain B showed the highest plant height and number of leaves while the interaction between Arusha Dc × control showed the highest leaf surface area. The interaction between Variety × Strain did not significantly (p<0.05) affect both plant height, number of leaves and leaf surface area. The interaction between Site × Variety × Strain did not significantly (p<0.05) affect both plant height, number of leaves, and leaf surface area.

Table 18: The interaction effect of study sites and banana varieties on banana plant growth parameters following field establishment

Study sites	Banana varieties	Plant height (cm)	Number of leaves	Leaf surface area (cm^2)
Nduruma	Williams	132.2a	8.986a	4783b
	Grand Naine	138.2a	9.542a	4890b
Masama kati	Williams	144.8a	9.333a	3425a
	Grand Naine	135.1a	8.639a	3311a
Grand mean		137.6	9.12	4102
CV %		1.6	0.8	11
P-value (Study sites)		0.725	<.001	<.001
P-value (Banana varieties)		0.918	0.195	0.987
P-value (Banana Variety x Study sites)		*0.092*	*0.029*	*0.611*

Values in the same column, followed by the same letter(s) do not differ significantly (p<0.05) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

Table 19: The interaction effect of study Site and AMF strains on banana plant growth parameters following field establishment

Study sites	AMF strains	Plant height (cm)	Number of leaves	Leaf surface area (cm^2)
Nduruma	A	136.1ab	9.361a	4609cd
	B	142.9ab	9.944a	5758d
	C	135.9ab	8.444a	4347bc
	Control (No strains)	126.0ab	9.306a	4631cd
Masama kati	A	140.7ab	9.194a	3526abc
	B	151.6b	9.389a	3856abc
	C	151.1b	9.389a	2946a
	Control (No strains)	116.5a	7.972a	3143ab
Grand mean		137.6	9.12	4102
CV %		1.6	0.8	11
P-value (Study sites)		0.725	<.001	<.001
P-value (AMF strains)		<001	0.026	0.061
P-value Study sites x AMF strains)		*0.009*	*0.558*	*0.017*

Values in the same column, followed by the same letter(s) do not differ significantly ($p<0.05$) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus*

Table 20: The interaction effect of Banana Varieties and AMF Strains on banana plant growth parameters following field establishment

Study sites	AMF strains	Plant height (cm)	Number of leaves	Leaf surface area (cm^2)
Williams	A	135.0ab	9.306a	4138a
	B	141.4ab	9.528a	4244a
	C	143.7ab	9.194a	4169a
	Control (No strains)	134.0ab	8.611a	3865a
Grand Naine	A	141.8ab	9.250a	3997a
	B	150.2b	9.500a	4658a
	C	118.4a	9.306a	4319a
	Control (No strains)	136.2ab	8.306a	3428a
Grand mean		137.6	9.12	4102
CV %		1.6	0.8	11
P-value (Banana variety)		0.918	0.195	0.987
P-value (AMF strains)		<001	0.026	0.061
P-value (Varieties x AMF strains)		0.267	0.879	0.542

Values in the same column, followed by the same letter(s) do not differ significantly ($p<0.05$) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

Table 21: The interaction effect of study Sites, banana varieties and AMF strains on banana plant growth parameters following field establishment

Study sites	Study sites	AMF strains	Plant height (cm)	Number of leaves	Leaf surface area (cm^2)
Nduruma	Williams	A	127.2ab	8.889a	4722abc
		B	139.3ab	9.222a	5337bc
		C	138.2ab	9.222a	4393abc
		Control	124.3ab	8.611a	4680abc
	Grand Naine	A	145.1ab	9.833a	4496abc
		B	147.6ab	10.000a	6179c
		C	132.4ab	9.667a	4869abc
		Control	127.7ab	8.667a	4014ab
Masama kati	Williams	A	142.9ab	9.722a	3555ab
		B	158.6b	9.833a	3945ab
		C	149.3ab	8.000a	3050a
		Control	128.6ab	9.778a	3150a
	Grand Naine	A	138.4ab	8.667a	3498ab
		B	152.9b	8.944a	3768ab
		C	104.4a	7.944a	2842a
		Control	144.6ab	9.000a	3136a
Grand mean			137.6	9.12	4102
CV %			1.6	0.8	11
P-value (Study sites)			0.725	<.001	<.001
P-value (Banana variety)			0.918	0.195	0.987
P-value (AMF strains)			<001	0.026	0.061
P-value (Sites x Varieties x AMF strains)			*0.934*	*0.33*	*0.66*

Values in the same column, followed by the same letter(s) do not differ significantly (p<0.05) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

4.1.7 Effects of Study Sites, Banana Varieties and AMF Strains on Fruit Yield and Yield Parameters

Table 22, 23 and 24 shows the findings for the number of fingers and hands, bunch weight (kg), and total fruit output (t ha^{-1}) as a function of the research locations, banana types, and AMF strains. The yield and yield characteristics were not substantially affected ($p<0.05$) by locations or banana types, according to the data. The number of fingers, bunch weight, and yield were substantially ($p<0.05$) impacted by the AMF strains. In terms of banana finger count, bunch weight, and yield, AMF strain B (*Rhizophagus intraradices*) had the best results (147, 25.44 kg, and 28.238 t ha^{-1}, respectively), whereas strain C (*Rhizophagus clarus*) had the worst results (126.2, 22.43 kg, and 24.897 t ha^{-1}, respectively).

Table 22: The effect of sites on yield and yield parameters of the tested banana varieties grown in Nduruma and Masama kati wards

Study sites	Fingers	Hands	Bunch Weight (Kg)	Yield (T/Ha)
Nduruma	139.85a	9.26a	24.79a	27.5169a
Masama kati	135.20a	8.99a	24.02a	26.6622a
Grand mean	137.6	9.12	24.39	27.0729
CV %	2.4	6	2.5	2.5
p - value	*0.307*	*0.331*	*0.394*	*0.394*

Values in the same column, followed by the same letter(s) do not differ significantly (p<0.05) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

Table 23: The effect of variety on yield and yield parameters of the tested banana varieties grown in Nduruma and Masama kati wards

Banana varieties	Fingers	Hands	Bunch Weight (Kg)	Yield (T/Ha)
Williams	138.55a	9.15a	24.69a	27.4059a
Grand Naine	136.55a	9.08a	24.02a	26.6622a
Grand Mean	137.6	9.12	24.39	27.0729
CV %	2.4	6	2.5	2.5
p - value	*0.684*	*0.808*	*0.394*	*0.394*

Values in the same column, followed by the same letter(s) do not differ significantly (p<0.05) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

Table 24: The effect of AMF strain on yield and yield parameters of the tested banana varieties grown in Nduruma and Masama kati wards

AMF strains	Fingers	Hands	Bunch Weight (Kg)	Yield (T/Ha)
A	138.4ab	9.278a	25.25ab	28.0275ab
B	147.0b	9.417a	25.44b	28.2384b
C	126.2a	8.458a	22.43a	24.8973a
Control	138.8ab	9.347a	24.44ab	27.1284ab
Grand Mean	137.6	9.12	24.39	27.0729
CV %	2.4	6	2.5	2.5
p - value	*0.018*	*0.062*	*0.034*	*0.034*

Values in the same column, followed by the same letter(s) do not differ significantly (p<0.05) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

4.1.8 The Interaction Effect of Sites, Variety and AMF Strain on Yield Parameters of the Tested Banana Varieties

Tables25, 26, 27, and 28 demonstrate the findings for the interaction impact of location, variety, and AMF strain on banana production, bunch weight, number of fingers, and number of hands. Except for the site-strain interaction for the number of fingers and hands, none of the investigated interaction effects substantially affected bunch weight, banana yield, number of hands, number of fingers, or number of fingers *(p*<0.05).

Table 25: The interaction effect of the study sites and banana varieties on yield parameters

Study sites	Banana varieties	Fingers	Hands	Bunch Weight (Kg)
Nduruma	Williams	14.14a	98.2a	23.04a
	Grand Naine	14.15a	104.1a	25.05a
Masama kati	Williams	12.49a	105.7a	25.06a
	Grand Naine	11.47a	99.0a	24.40a
Grand Mean		13.06	101.7	24.39
CV %		2.4	6	2.5
P-value (Sites)		*0.307*	*0.331*	*0.394*
p - value(Variety)		*0.684*	*0.808*	*0.394*
P-value (sites X Variety)		0.183	0.065	0.099

Values in the same column, followed by the same letter(s) do not differ significantly ($p<0.05$) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

Table 26: The interaction effect of study sites and AMF strains on banana yield parameters

Study sites	AMF strains	Hands	Fingers	Bunch weight (kg)
Nduruma	A	14.22a	96.8abc	23.67ab
	B	14.94c	111.4bc	24.71ab
	C	13.67bc	103.9abc	24.42ab
	Control	13.75bc	92.5ab	23.39ab
Masama kati	A	12.50ab	110.4bc	25.71ab
	B	13.17bc	114.2c	26.46b
	C	10.33a	86.3a	21.19a
	Control	11.92ab	98.4abc	25.79ab
Grand Mean		13.06	101.7	24.39
CV (%)		2.4	6	2.5
p - value (Sites)		*0.307*	*0.331*	*0.394*
P - value (AMF strains)		*0.018*	*0.062*	*0.034*
P-value (sites x AMF strains)		0.032	0.015	0.148

Values in the same column, followed by the same letter(s) do not differ significantly ($p<0.05$) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

Table 27: The interaction effect of study sites, banana varieties on yield parameters

Banana varieties	AMF strains	Hands	Fingers	Bunch weight (kg)
Williams	A	13.56a	104.7ab	24.10a
	B	13.72a	92.4ab	22.92a
	C	13.44a	110.2b	24.90a
	Control	12.53a	100.4ab	24.29a
Grand Naine	A	13.17a	102.5ab	26.40a
	B	13.39a	107.9b	25.96a
	C	11.56a	68.4a	21.96a
	Control	13.14a	109.5b	24.58a
Grand Mean		13.06	101.7	24.39
CV (%)		2.4	6	2.5
p - value (varieties)		*0.684*	*0.808*	*0.394*
P - value (AMF strains)		*0.018*	*0.062*	*0.034*
P-value (Varieties x AMF strains)		0.863	0.428	0.543

Values in the same column, followed by the same letter(s) do not differ significantly ($p<0.05$) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus*

Table 28: The interaction effect of study sites, banana varieties and AMF strains on yield parameters

Study sites	Banana varieties	AMF strains	Hands	Fingers	Bunch weight (kg)
Nduruma	Williams	A	14.00a	93.6a	23.00a
		B	14.78a	103.5a	23.58a
		C	13.39a	93.2a	23.42a
		Control	14.39a	102.4a	22.17a
	Grand Naine	A	14.44a	99.9a	23.92a
		B	15.1a	120.4	26.42a
		C	13.94a	104.3a	25.25a
		Control	13.11a	91.8a	24.61a
Masama kati	Williams	A	13.11a	115.8a	25.19a
		B	13.50a	116.9a	26.25a
		C	10.67a	91.5a	22.39a
		Control	12.67a	98.3a	26.42a
	Grand Naine	A	11.89a	105.0a	26.39a
		B	12.83a	111.5a	26.67a
		C	10.0a	81.0a	20.00a
		Control	11.17a	98.6a	24.56a
Grand Mean			13.06	101.7	24.39
CV (%)			2.4	6	2.5
P-value (Sites)			0.183	0.065	0.099
p - value (varieties)			*0.684*	*0.808*	*0.394*
P - value (AMF strains)			*0.018*	*0.062*	*0.034*
P-value (Sites x Varieties x AMF strains)			*0.661*	*0.911*	*0.924*

Values in the same column, followed by the same letter(s) do not differ significantly ($p<0.05$) according to Tukey's honestly significance test. A = *Rhizophagus irregularis,* B = *Rhizophagus intraradices*, C = *Rhizophagus clarus.*

4.2 Discussion

4.2.1 Effects of Varieties, Growth Media and AMF Strains on Banana Plantlets Height and Leaf Surface Area after Establishment of the Nursery Experiment

The results showed that some AMF strains dramatically improved banana plant development, as measured by plantlet height. The results might be explained by the fact that the AMF strains improve plant growth and development by making it easier for plants to absorb vital nutrients from the growing medium. Consistent with previous research by Marzban *et al.* (2017) and Ebbisa (2022). The scientists found that plants were able to absorb more phosphorus from the soil after receiving mycorrhizal inoculation. Among the many benefits that AMFs provide to plants, are protecting them from root diseases, boosting their ability to absorb water and nutrients (particularly P) from the soil, and reducing the impact of temperature, pH, and moisture stress extremes (Yano-Melo *et al.,* 1999).

For the tested banana varieties, there was a significance effect in plant height. Williams banana variety showed a notably positive in growth plant height and reached the stage of four fully developed leaves in a shorter period. The results of this study align with those documented earlier in Rayan *et al.* (2017) who reported Williams banana variety recorded highest value in growth characteristics such as plant height and plant girth. However, the insignificance observed in leaf surface area between the tested banana varieties could be attributed to the inherent characteristic as Grand Naine and Williams banana varieties share genetic similarities, indicating that they are descended from the Cavendish subgroup. Their physical features are heavily influenced by their shared AAA genomic configuration, thus it's difficult to be altered by AMF strain. This is in line with research by Jefwa *et al.* (2012), that indicates the degree of AMF-mediated foliar feature changes may be limited by genetic composition.

Likewise, growth media significantly affected growth parameters (leaf surface area), whereby plantlets grown in polyethylene pots containing forest soil were taller than those grown in Jiffy pots containing cocopeat. The observed results might have been attributed by the fact that forest soil contained large quantities of essential plant nutrients compared with cocopeat, thus enhanced plantlets growth and development. The findings align with those of Chincholkar *et al.* (2000) and Vasane and Kothari (2006), who observed that soil combined with organic manure yielded superior results as a rooting medium for banana growth and development compared to cocopeat in jiffy pots.

In a similar vein, Bhardwaj *et al.* (2012) discovered that, in comparison to peat-based substrates, tomato seedlings' root development and shoot growth were much improved by forest soil supplemented with organic amendments. This was probably because of increased microbial activity and nutrient retention. Contrary to that, Mengesha *et al.* (2013) found that Jiffy-7 peat pellets resulted in robust plant development and a survival rate of over 8%, surpassing the performance of soil mix for small-scale applications. Furthermore, Kumar and

Singh (2017) highlighted that, unlike nutrient-rich forest soil, cocopeat provides great aeration and water retention but sometimes requires extra fertilization due to its low nutritional content.

The higher performance of forest soil in this study could also be attributed to its native microbial populations, which may combine synergistically with AMF to improve nutrient availability (Marzban *et al.*, 2017; Ebbisa, 2022). Smith and Read (2008) found that the varied microbial communities in forest soil promote phosphorus uptake through AMF symbiosis, hence increasing plant vigor. Gaur and Adholeya (2004) discovered that while cocopeat can be enhanced with specialized microbial inoculants, its baseline microbial activity is lower than that of forest soil, potentially limiting its efficacy in the absence of supplements.

4.2.2 Effects of Study Sites, Banana Varieties and AMF Strains on Plant Growth Parameters on Field Experiment

The findings of this study revealed that experimental sites had a significant effect on the investigated growth parameters (except, plant height). Banana plants grown in the Nduruma site produced more and larger leaves than those grown in Masama kati site. The observed variations could be explained by the contrasting weather conditions whereby the Nduruma site received more and well distributed rainfall in a long period of the year compared with the Masama kati site.

Consequently, banana plants grown in the Nduruma site had uniform growth and development as reflected on the number of leaves and leaf size. These findings are in corroboration to that of Mngumi, (2016) who reported that erratic rains caused by climate change in the past three decades has negatively impacted banana production in the Kilimanjaro region. Also, report from Ravi and Mustaffa, (2013) revealed that areas experiencing both water shortage and high temperature may pose further problem in banana production. According to Bowles *et al.* (2016), the higher water-use efficiency facilitated by AMF likely contributed to greater plant performance at Nduruma site, where adequate moisture supplemented AMF's role in sustaining cell turgor pressure under suboptimal conditions (Bi *et al.*, 2019).

The findings of this study further revealed that growth parameters *viz*. number of leaves, leaf size, and plant height of the tested banana varieties did not differ significantly within the respective experimental site. The insignificance difference observed might have been caused by the genetic makeup of the two varieties as both are having alike pseudo stem growth habit and foliar characteristic. This genetic closeness is likely to restrict the differential impact of

AMF on these parameters, as suggested by Jefwa *et al.* (2012), who observed that closely related banana cultivars may respond similarly to AMF inoculation.

Furthermore, this study's results showed that all of the AMF strains examined had a favorable and statistically significant effect on banana leaf number and plant height, with AMF strain B (*Rhizophagus intraradices*) outperforming the others. Increased fertilizer and water intake after root colonization may explain why banana plants infected with R. intraradices showed better crop stand. These findings are in line with those of Leigh *et al.* (2009) and Aguirre-Cadena *et al.* (2021), which both underscore the important function of *R. intraradices* in the soil ecosystem and its symbiotic relationships with plants, improving plant growth, stress tolerance, and sustainable farming methods.

Another study by Medina *et al.* (2005) found that inoculation with R. intraradices greatly impacted the development of common bean (*Phaseolus vulgaris* L.) plants. For instance, inoculated common bean plants were observed to have four more leaves as compared to the control. Similarly, Schenck (2010) found that micro propagated *Prunus cerasifera* L. transplants fared better after AMF colonization by *R. intraradices* than controls that were not infected. In addition, compared to control treatments, inoculated plants showed markedly better growth and metabolism when exposed to AMF, with increased concentrations of fat, crude protein, crude fiber and carbs in their root and shoot systems. Therefore, inoculating seedlings and plantlets in nurseries is a great way to make plants that will do well when planted in the field since they will be more likely to survive and flourish.

4.2.3 The Effect of Sites, Variety, and AMF Strain on Yield and Yield Parameters of Banana in the Field Experiment

In terms of banana production, bunch weight, number of fingers, and number of hands, there was no statistically significant relationship between the two locations and the tested kinds. This suggests that site-specific conditions and varietal differences may not be the primary drivers of yield variation in this study, which is consistent with the findings of Wachenje *et al.* (2018), who found that environmental factors such as soil type and microclimate play a more important role in AMF efficacy than geographic location. Plant responses to AMF inoculation vary greatly depending on banana variety, AMF strain, and field circumstances, which may explain the lack of substantial yield differences in this experiment (Jaizme-Vega *et al.*, 2003; Vosátka *et al.*, 2012).

In contrast to what most studies have shown, these results show that AMF strains can affect nutrient absorption, tolerate stress from the environment, and control migratory endoparasitic nematodes, all of which contribute to banana growth and yield (Koffi *et al.,* 2013; Schouteden *et al.,* 2015; Thangavel *et al.,* 2022). A meta-analysis by Zhang *et al.* (2019) found that AMF inoculation increases phosphorus uptake in bananas by up to 40%, even in low-fertility soils, supporting our data on increased nutrient acquisition.

However, AMF's role in improving nutrient uptake, stress tolerance, and migratory endoparasitic nematode control most likely contributed to the overall health and productivity of banana plants, even if yield differences were not statistically significant (Thangavel *et al.*, 2022; Declerck *et al.*, 2002). In the study of AMF strains, strain B stood out with its high bunch weight, number of fingers, and hands. This could be because AMF improves root absorption capabilities by increasing nutrient and water uptake through their extensive hyphal networks.

With extraradical hyphae reaching up to 8 cm beyond the root and accessing a larger volume of soil nutrients than the 1-2 mm depletion zone surrounding non-mycorrhizal roots, AMF, for example, can provide up to 90% of a plant's phosphorus needs (Lehmann *et al.*, 2019). Studies by Augé *et al.* (2016) have shown that AMF hyphae can extend up to 8 cm from the root, accessing nutrients in soil volumes up to 100 times larger than non-mycorrhizal roots, which aligns with our findings on improved phosphorus acquisition. Additionally, Strain B may have stimulated plant growth hormones such as auxins and cytokinins, as demonstrated by Ludwig-Müller (2010), leading to enhanced photosynthetic efficiency and biomass accumulation.

One possible explanation for the favorable reaction to these yield characteristics might be AMF's capacity to affect plant growth hormone synthesis, which in turn enhances growth and photosynthetic efficiency. A more favorable environment for banana plant development is created by these combined impacts, leading to larger yields. The use of AMF isolates in conjunction with lower chemical fertilizer dosages has shown significant promise as an alternate method for soil fertility management in tomato crops, according to Thangavel *et al.* (2022), who also found similar results.

The results showed that AMF inoculation improved water usage efficiency, fruit quality, and yield in watermelon. These findings emphasize the potential of AMF, specifically Rhizophagus intraradices, as a long-term strategy for improving banana yield and quality in nutrient-poor soils like those seen in Tanzania (Meya, 2021). The delayed but considerable AMF colonization observed by week 8 post-inoculation shows that extended interaction durations are required to enhance benefits, highlighting the need of optimum inoculation tactics in banana farming (Smith & Read, 2008; Zhang *et al.*, 2020).

This study demonstrates the significant benefits of AMF strains in terms of banana plantlet development, yield, and resilience across different cultivars, growth conditions, and experimental settings in terms of nutrient and water uptake, photosynthesis through increased chlorophyll, and stress tolerance via hormonal regulation, particularly in the Williams variety and forest soil at the Arusha DC site (Smith a& Read, 2008; Wahab *et al.*, 2023; Baum *et al.*, 2015). The AMF is a sustainable, cost-effective way to optimizing banana production by minimizing chemical inputs and enhancing soil health. More research on native strains and inoculation procedures is needed to enhance these benefits (Zhang *et al.*, 2020; Jefwa *et al.*, 2012).

Given these benefits, AMF is a sustainable and cost-effective technique for maximizing banana production by minimizing chemical inputs and boosting long-term soil health. However, the efficiency of AMF is dependent on the compatibility of native soil fungi with foreign strains, demanding additional study on locally adapted AMF isolates (Jefwa *et al.*, 2012). Similarly, a study by Diedhiou *et al.* (2016) stressed the importance of optimizing inoculation strategies, such as seed coating or root dipping for consistent field performance.

In conclusion, this study shows that AMF inoculation can be successfully integrated into banana production systems, increasing nutrient usage efficiency and output potential. Future studies should focus on discovering high-performing native AMF strains and improving application methods to optimize benefits under different.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study aimed at gathering quantitative evidence on the benefits of AMF technology in promoting plant growth rate during nursery management and enhancing banana yield in the field conditions, while lowering the production costs during screen house management reflected in days to 4 leaves stage. The positive finding that AMF shortens the period to four fully developed leaves during the nursery phase can be attributed to enhanced nutrient uptake facilitated by AMF, this accelerated growth and development result in quicker leaf maturity, which is beneficial for nursery operations by reducing production time and potentially improving overall plant health and vigor. Also, plants grown in polyethylene pots containing forest soil had a better development than those grown in Jiffy pots. This could be related to the limited size of the Jiffy pots, thus the quantities of plant nutrient supply. This further suggested that increasing the size of the Jiffy pots would be a good option, since the plants are easy to manipulate. Also, transportation of the banana plantlets to the field is less stressful when using Jiffy technology.

The growth in the field and in most AMF-inoculated treatments, no significant differences were observed. This could be due to the plants being inoculated only once during the nursery transplanting, it is possible that this is the reason the plants did not perform well in the field. They had to form new roots, or the existing roots, which already had mycorrhizal fungi, may have been damaged during field transplanting. Also there is a possibility of competition between the strains used and the natural strains that were found in the soils in the field thus made the presents strains failed to work effectively.

Thus the findings from this study suggests that AMF primed banana plantlets lowers the production costs of TC sourced banana plantlets which can reduce the price of banana tissue culture plantlets as planting materials paid by mostly smallholder farmers who cannot afford expensive fertilizers and pesticides which will boost the smallholder farmers economy since production and management cost is lowered due to increased survival of the robust yielding bananas. As AMF are naturally occurring organisms, they are environmentally friendly. Therefore the use of AMF is thus expected to have not only economic but also environmental impacts.

5.2 Recommendations

The results and findings obtained are promising. It’s recommended to consider:

(i) Inoculation be carried out concurrently with field transplanting to guarantee that plants are successfully colonized by mycorrhizal fungi, improving outcomes for AMF strains in the field as well.

(ii) The size of Jiffy pallets should be optimized to give out positive results to the plants during the nursery phase, since they are said to be beneficial for plant propagation due to their ability to reduce transplant shock, environmentally friendly since they are biodegradable, and contribute easy handling, making sustainable choices for nurseries and greenhouse operations.

(iii) The AMF strains used were imported, it is possible that the imported strains failed to cope with the field conditions to achieve the best results, it is advisable to develop strains that are native to the specific environment.

(iv) Conduct additional field trials in different regions and under varying environmental conditions to validate the positive effects of AMF inoculation on banana growth and yield, ensuring the results are applicable across diverse farming landscapes.

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RESEARCH OUTPUTS

(i) Publications

Accepted manuscript

"Arbuscular Mycorrhizal Fungi Inoculation Enhanced Banana Plant Growth and Fruit Yield in Central-northern Tanzania"

(ii) Poster presentation