

**GROWTH, YIELD AND NUTRITIONAL COMPOSITION OF *Moringa oleifera*
UNDER DIFFERENT PROPAGATION METHODS**

by

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DECLARATION

I declare that the mini-dissertation, titled “growth, yield and nutritional composition of *Moringa oleifera* under different propagation methods”, hereby submitted to the University of Limpopo, for the degree of Master of Science in Agronomy has not previously been submitted by me for a degree at this or any other university; that it is my work in design and in execution, and that all material contained herein has been duly acknowledged.

Candidate: Mahlangu N

Signature

Date

DEDICATION

With heartfelt gratitude, I dedicate this mini dissertation to my family, whose unwavering support and encouragement have been the pillars of my academic

journey. To my friends, mentors, and loved ones, your belief in my capabilities has been a constant source of inspiration. This achievement is as much yours as mine. May this work stand as a testament to the collective strength of those who have guided and cheered me on along this scholarly path.

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LIST OF ABBREVIATIONS

%	Percentage
°C	Degree Celsius
ADF	Acid Detergent Fibre
AOAC	Association Official Analytical Chemists
ARU	Aquaculture Research Unit
Ca	Calcium
CCI	Chlorophyll Content Index
Cu	Copper
Cv%	Coefficient of Variation
DAT	Days After Transplanting
DRW	Dry root weight
EC	Electric Conductivity
FAO	Food and Agriculture Organization
Fe	Iron
FRW	Fresh root weight
g/kg	Gram per kilogram
H ₂ O	Water
K	Potassium
Mg	Magnesium
mg/kg	Milligram per kilogram
ml	Milliliter
mm	Millimeter
Mn	Manganese
Na	Sodium
NDF	Neutral detergent fibre
NH ₄ -N	Ammonium nitrogen
NO ₃ -N	Nitrate nitrogen
P	Phosphorus
pH	Potential of Hydrogen
WAP	Weeks after planting
Zn	Zinc
µS/cm	Micro-Siemens per centimeter

ABSTRACT

Moringa oleifera, often referred to as the "drumstick tree" or "miracle tree," has gained prominence for its nutritional and medicinal properties. This study aimed to assess the impact of different propagation methods on the growth, yield and nutritional composition of *Moringa oleifera* and recommending the best method that can be used for propagating the tree. Three propagation techniques, including direct seeding, stem cuttings, and seedling transplanting, were investigated. This research was carried out at the University of Limpopo Aquaculture Research Unit (ARU), located in Mankweng area, Limpopo Province, South Africa. The growth parameters, including emergence, sprouting, and rooting rates, height of the shoots, number of branches per plant, stem diameter, and chlorophyll content, were monitored at three weeks intervals. Additionally, yield components such as fresh and dry weight of the shoots and roots were quantified. Nutritional composition, proximate composition encompassing macro and micronutrients, was analyzed in harvested plant leaves. Results indicated that seedling transplanting-propagated plants exhibited the highest initial growth rates, while cuttings and direct seeding plants displayed slower but consistent growth. However, significant variations in yield were observed, with seedling transplanted plants demonstrating higher fresh shoot and root weight and higher dry shoot and root weight. Nutritional analysis revealed subtle differences in the composition of leaves among the propagation methods, with implications for the overall nutritional quality of harvested products. The findings of this study contribute valuable insights into the cultivation practices of *Moringa oleifera*, providing information on the most effective propagation methods for desired outcomes in terms of growth, yield, and nutritional composition. This knowledge can aid farmers, researchers, and policymakers in optimizing *Moringa oleifera* cultivation for enhanced nutritional benefits and sustainable agricultural practices.

Keywords: Growth parameters, *Moringa oleifera*, nutritional composition, propagation methods, sustainable agriculture, yield components

CHAPTER 1: GENERAL INTRODUCTION

1.1. Background of the study

The multipurpose plant *Moringa oleifera* may produce industrial raw materials from each of its parts, including leaves, seeds, pods, flowers, bark, and roots (Mai Bukar *et al.*, 2015). It is the most extensively grown species in the 13-species tropical flowering plant family *Moringaceae* (Shahzad *et al.*, 2013). Pakade *et al.* (2013) reported on increased interest in Moringa cultivation. While *Moringa oleifera* is grown in KwaZulu-Natal, Gauteng, Limpopo, Northwest and the lowveld of Mpumalanga provinces in South Africa, it is primarily grown in Limpopo province. It is a valuable tree that is rich in nutrients that are beneficial to health and necessary for human survival. As a result, its establishment and growth will be advantageous, particularly to the numerous developing countries that are affected by poverty (Rufai *et al.*, 2016). According to Price (2007), the various portions of *Moringa oleifera* contain thirty-two (32) chemical compounds that have nutritional significance. The high protein content of Moringa leaves and pods is highly intriguing; as a result, eating these plant parts can fight malnutrition as they are a cheap source of protein (Price, 2007). Moringa is well known for its nutritional value for humans and animals. It is used as food, feed, fodder, fertilizer, fuel, oil in the industry, for reforestation, as ornamental, water purifier, biopesticide and as treatment of various ailments in medicine throughout the world (Fuglie, 1999). It is adapted to a wide range of soil types but grows best in well-drained loam to clay loam, neutral to slightly acidic soils, but cannot withstand prolonged waterlogging (Adebayo, 2011; Padilla, 2012). Moringa is propagated sexually through seeds and vegetatively through stem cuttings, however, the spread of Moringa is also rare for seed germination and viability or survival are low, and there is the lack of vegetative propagation method (Devendra, 2012).

Utilizing nursery methods or botanical propagation for the cultivation of superior seedlings holds significance in the advancement of perennial crops, such as Moringa. This is particularly crucial given the increasing popularity of Moringa trees as a renowned source of nourishing food and diverse applications. According to Rodrigues-Perez (2005), germination and seedling resilience represent a plant's capacity to persist, which is pivotal, especially in arid ecosystems, during crucial stages of the plant's life cycle. Additionally, the preparation of seedlings holds significance in the production of nursery stock. Prasad *et al.* (2012) suggests that among generative and

vegetative propagation techniques, utilizing stem cuttings is advisable for accelerated establishment and proliferation of numerous species in arid environments. Moringa, characterized by extensive cross-pollination resulting in heterozygosity (Fuglie, 1999), is well-suited for propagation through stem cuttings. This method ensures the generation of offspring with identical traits to the parent plant, leading to uniformity in both yield quantity and quality (Barche *et al.*, 2013). Hence, the meticulous preparation of superior seedlings using vegetative propagation methods, particularly through the utilization of efficient and proficient cuttings, stands as a crucial determinant for the prosperity of Moringa cultivation.

1.2. Problem statement

Lack of access to healthy, balanced diet continues to be a significant health barrier to majority of the rural communities (Govender *et al.*, 2016). Communities with limited access to resources in South Africa cannot afford a healthy diet and rely more on social grants, which cannot purchase expensive food. On the other hand, continued population increase becomes a threat to food security, leading into malnutrition (Govender *et al.*, 2016). While agriculture remains the primary livelihood for rural communities, FAO (2016) indicates that 50% of those experiencing hunger are farming families residing in rural areas. It is contended that although poverty stands as the primary contributor to hunger, hunger itself perpetuates poverty by inducing poor health and diminished energy levels, consequently hindering productivity, and perpetuating the cycle of poverty.

According to Lekgau (2011), communities and farmers in South Africa have expressed interest in producing Moringa on tiny plots of land and in backyards. However, the low awareness levels of the plant inherent benefits have challenged the level of its production in some parts of rural communities in South Africa. Other challenges to the production of the plant include inadequate knowledge about its cultivation and uses (Thapa *et al.*, 2019). According to Fotouo-M *et al.* (2015), the viability of seeds tends to deteriorate quickly. Another problem is that seeds do not accurately represent the traits of their mother trees when they are regularly sowed.

1.3. Rationale

The development of a perennial crop, such as Moringa, requires careful plant propagation to provide a high-quality seedling since the tree is well-known for its use

in the production of nutrient-rich food and other products (Santoso and Parwata, 2020). Moringa plays a significant part in ensuring food security and enhancing the lives of smallholder farmers, but its benefits extend beyond that. It is a highly nutritious plant that can contribute to improving nutrition, especially in areas where malnutrition is prevalent. *Moringa oleifera* growth is limited since it frequently reproduces from seeds (Stephenson and Fahey, 2004). Since Moringa may be multiplied vegetatively through stem cuttings, this phenomenon has been improved. Nowadays, farmers choose vegetative propagation of Moringa over seed propagation because seedlings produced by vegetative propagation more accurately reflect the traits of the mother trees. When seeds are sown normally, they do not really reflect the characteristics of their mother trees. When compared to seedling transplanting, direct seeding is a popular approach because of its lower cost and easy establishment (Rufai *et al.*, 2016). Mbakwe and Nzekwe (2005) observed that the large-scale establishment of economically valuable species can aid in the preservation of plant species that are anticipated to support industrial activity. Bukar and Abba (2022) also stated that a lot of uniform seedlings should be produced to conserve plants. They also noted that accurate knowledge of the methods for propagating the chosen plant species is required to create many consistent seedlings.

According to FAO (2016), cutting propagation is a better method for growing high yielding varieties of chosen mother trees. Direct seeding can produce plants with high yields and greater pest and disease tolerance, despite the possibility of a reduced survival rate. For rapid establishment and production, on the other hand, the stem cutting method of propagation is advised. One of the unknowns for mass planting *Moringa oleifera* is the ideal propagation method and an alternative method of propagation through cuttings has also not been tried to determine whether it is a better alternative to seed propagation. Due to the limited distribution of Moringa, efforts must be made to ensure that the necessary conservation plant propagation techniques result in a rapid production of Moringa (Muslihatina *et al.*, 2017). Moreover, there is limited information on propagation of the Moringa tree using the different procedures available for farmers in rural communities of the Limpopo Province. Farmers in Limpopo Province use various methods of propagation such as direct seeding, seedling transplanting, and stem cuttings to establish Moringa orchard. However, the information on how these methods of propagation enhance growth, yield, and

nutritional composition of Moringa is limited. This has led to the Moringa population and yield remaining low or improving with multiple attempts to establish the plant (Kiragu *et al.*, 2015). The objective of this study is to observe the growth, yield, and nutritional composition of *Moringa oleifera* under different propagation methods. Therefore, the use of various propagation methods will be used to assess the best method of propagation that can enhance growth, yield, and nutritional composition of Moringa.

1.4. Aim

This study aims to investigate the effect of propagation methods on the growth, yield, and nutritional composition of the Moringa tree and recommending the best method that can be used for propagating the tree.

1.5. Objective

To determine the best propagation method(s) that can maintain high growth and yield of the Moringa tree, and high nutritional composition of Moringa leaves.

1.6. Hypothesis

Propagation method(s) will have no effect on growth and yield of Moringa tree, and in maintaining the high nutritional composition of Moringa leaves.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This chapter reviews existing literature on the origin and geographical distribution of *Moringa oleifera*, description of *Moringa oleifera* tree, propagation methods and growth performance of *Moringa oleifera*, and the importance and uses of *Moringa oleifera* in terms of poverty alleviation, medicinal uses, socio-economic, and value-added products.

2.2. Origin and geographical distribution of *Moringa oleifera*

Moringa oleifera, commonly known as the drumstick tree, is believed to have originated in the Indian subcontinent, particularly in the northwestern region of India. It has been cultivated and utilized for centuries in traditional medicine and as a source of nutrition due to its valuable nutritional and medicinal properties (Olson, 2012). The plant's adaptability to various climatic conditions, along with its resistance to drought and poor soil quality, has contributed to its extensive distribution across tropical and subtropical regions worldwide. *Moringa oleifera* is now found in multiple continents and countries due to its adaptability and benefits (Anwar *et al.*, 2007). *Moringa oleifera* has been introduced to numerous African countries, where it thrives in arid conditions and is valued for its nutritional benefits. It is found in countries including Nigeria, Senegal, Kenya, Ghana, and Ethiopia (Leone *et al.*, 2015). The plant has been introduced to several South American countries, including Brazil, Colombia, and Peru. Furthermore, *Moringa oleifera* is cultivated in countries across Central America and the Caribbean, including Mexico, Honduras, and Jamaica. Beyond its origin in the Indian subcontinent, *Moringa oleifera* is present in various Southeast Asian countries such as Indonesia, the Philippines, and Thailand (Stohs and Hartman, 2015). The plant has been introduced to Pacific Island nations, including Fiji, Samoa, and Tonga, where its nutritional value contributes to its importance (Ogbunugafor *et al.*, 2017). *Moringa oleifera*'s widespread distribution can be attributed to its adaptability to a range of climates and soil conditions.

2.3. Description of *Moringa oleifera* tree

Moringa oleifera is a versatile and highly valued plant with a rich history of traditional use and extensive modern research. Belonging to the family Moringaceae. The plant is characterized by its slender, fast-growing nature, reaching heights of up to 10-12 meters (Olson, 2012). Its compound leaves are feathery and composed of small

leaflets that vary in number depending on the maturity of the plant. The elongated, drumstick-like pods are one of the most recognizable features of *Moringa oleifera*. These pods contain numerous edible seeds and are an essential part of the plant's culinary and nutritional uses. Its leaves are densely packed with essential nutrients, including vitamins (A, C, E), minerals (iron, calcium, potassium), and amino acids, making them a valuable dietary supplement and source of nourishment, particularly in regions where malnutrition is a concern (Anwar *et al.*, 2007). Furthermore, *Moringa oleifera* possesses various bioactive compounds with potential health benefits. These include antioxidants such as quercetin and beta-carotene, as well as phenolic compounds and isothiocyanates known for their anti-inflammatory and potential anticancer properties (Fahey, 2005). Its seeds can be pressed to yield a high-quality oil known as "Ben oil," which has culinary, cosmetic, and industrial applications (Fuglie, 1999). In recent years, *Moringa oleifera* has gained global attention for its potential to address nutritional deficiencies, support sustainable agriculture, and contribute to poverty alleviation in various communities. Its adaptability to diverse climates and its ability to grow in arid conditions make it an essential resource for regions facing environmental challenges.

2.4. Propagation methods and growth performance of *Moringa oleifera*

Plant propagation has been an important human endeavor since ancient times (Singh, 2004), with the chosen method playing a crucial role in determining crop success and productivity. For perennial *Moringa*, various propagation techniques such as hardwood cutting, softwood cutting, air layering, and grafting are employed (Monisha *et al.*, 2019). Vegetative propagation serves as a viable approach to address noted limitations, streamline cultivation processes, and unlock its economic potential (Rufai *et al.*, 2016). Given the biotechnological opportunities presented by plant products, ensuring the availability of numerous uniformly growing seedlings is crucial for large-scale farm establishment, especially in the current context of conserving valuable plant species (Puri, 1990). Vegetative propagation offers advantages over sexual propagation by producing uniform rootstocks and ensuring the maintenance of high-yielding progenies true to their original type. Continuous agricultural research endeavors aim to produce disease-free, true-to-type plants from stem cuttings, including those traditionally challenging to root under normal conditions (Rufai *et al.*, 2016).

The choice of propagation method varies across different countries. Traditionally, in Sudan, seeds are the preferred option, whereas vegetative propagation is commonly practiced in countries like India, Indonesia, and certain regions of West Africa (Leone *et al.*, 2015). Seeds in Sudan undergo a 12-hour soaking period to overcome dormancy, and they typically germinate within two weeks when sown at a maximum depth of 2 cm. In nursery settings, seedlings are usually ready for transplanting when they reach approximately 30 cm in height, which occurs within 3-6 weeks after germination (Ojiako *et al.*, 2011). Optimal storage conditions, characterized by a temperature of 3°C and a moisture content of 5-8%, ensure a germination rate of 80-90% (Leone *et al.*, 2015). However, if seeds are stored at room temperature and high humidity levels, their viability diminishes significantly, with the germination rate reducing to 7.5% after three months (Morton, 1991).

The research conducted by Mabapa *et al.* (2017) investigated the propagation practices of farmers in Limpopo Province regarding Moringa cultivation. The findings revealed that farmers utilize a range of propagation methods including seeds, seedlings, and cuttings to establish Moringa plants. This aligns with the conclusions drawn by Gadzirayi *et al.* (2013), which highlighted seedling propagation as the most prevalent method for establishing Moringa plantations. Farmers tend to favor seedling propagation, especially during rainy and warm seasons, to facilitate better establishment. Direct planting is preferred to mitigate transplanting shock, which can hinder the crop's early development (Gadzirayi *et al.*, 2013). While stem cuttings offer uniformity, their slower growth rate prolongs the establishment period (Mabapa *et al.*, 2017). Research indicates that seed propagation may lead to growth and yield variations due to genetic diversity, whereas vegetative propagation methods, like stem cuttings, typically exhibit more consistent growth performance (Ndabikunze *et al.*, 2011; Franzel *et al.*, 1996).

Direct seeding is the preferred method when seed availability is high and labour resources are limited. *Moringa oleifera* readily establishes from seed without the need for any seed treatment (Chumark *et al.*, 2006). The seedlings germinate rapidly and can attain a height of 5 meters within a year if protected from drying winds and adequately watered. However, to ensure convenient harvesting and maintenance, it is customary to prune the tree to a height of one meter or less each year (Shen *et al.*, 2006). Growing Moringa in seed beds or containers offers protection against insects

and pests, although this method is notably time-consuming. When propagating Moringa, it's essential to bury at least one-third of the plant portion in the soil. Moringa seeds are typically planted about 2 cm below the soil surface and can germinate throughout the year in well-draining soil conditions (Raja *et al.*, 2016). Some research indicates that trees propagated from seeds develop longer roots compared to those from cuttings, making them potentially more suitable for planting in semiarid and arid regions where the depth of the water table may restrict growth (Jahn *et al.*, 1986). Seed propagation has been associated with yield variability due to genetic factors and environmental conditions (Ndabikunze *et al.*, 2011). In contrast, vegetative propagation methods, such as air layering and grafting, have shown potential to enhance yield consistency by preserving desirable traits (Eilittä *et al.*, 2002). Transplanting involves the process of collecting seeds from the Moringa tree, nurturing plantlets in a greenhouse for a period of two to three months, and subsequently transferring mature stems, typically measuring between 1 to 1.5 meters in length, to the main fields (Chumark *et al.*, 2006). While transplanting offers flexibility in field planting, it necessitates additional labor and expenses for raising seedlings. Alternatively, stem cuttings are employed when seed availability is limited but labor resources are abundant (Palada and Chang, 2003).

Taking vegetative cuttings of Moringa is a widespread practice in regions with high humidity and tropical climates. This method is notably faster compared to other propagation techniques, as Moringa trees can grow up to 3 meters in height within three months and reach maturity at an accelerated rate (Ratshilivha *et al.*, 2019). Additionally, Nzekwe (2002) observed that juvenile stem cuttings tend to root faster than mature stem cuttings. Successful vegetative propagation of *Moringa oleifera* using stem cuttings, both with and without hormonal treatment, has been demonstrated in South Africa, indicating the viability of this approach and the potential for producing ample planting materials (Bukar and Abba, 2022). Among the advantages of vegetative propagation through stem cuttings is the production of seedlings (rooted cuttings) that closely resemble the parent stock (Puffy *et al.*, 2008).

The research conducted by Kiragu *et al.* (2015) demonstrated that cultivating *Moringa oleifera* from seeds resulted in better performance compared to using cuttings, both in greenhouse and outdoor settings. Bukar and Abba (2022) concluded that *Moringa oleifera* can be vegetatively propagated by rooting stem cuttings. They found that

successful rooting of stem cuttings can be achieved during the wet season by implementing significant environmental changes. Furthermore, the presence of large-sized nodules on the stem cuttings can serve as an indicator of successful rooting and the production of high-quality seedlings. The study suggests that propagating the species through stem cuttings could conserve seeds for industrial purposes, while the production of large quantities of uniform seedlings (rooted cuttings) could significantly contribute to species conservation efforts (Bukar and Abba, 2022).

Research indicates that the nutritional composition of *Moringa oleifera* can be influenced by propagation methods. For instance, studies have shown variations in the content of bioactive compounds such as vitamins and minerals in plants propagated through different methods (Kumari *et al.*, 2018). Comparative studies between propagation methods have highlighted differences in growth, yield, and nutritional composition. Jacob *et al.* (2016) conducted a study comparing the efficacy of seed and stem cutting propagation methods on the initial growth rate of *Moringa oleifera*. They observed that *Moringa* seeds germinate more rapidly compared to sprouting from stem cuttings. Seedlings derived from seeds exhibit greater vigor and demonstrate a faster early growth rate in terms of height, number of leaflets, and stem collar diameter compared to seedlings originating from stem cuttings, which tend to be more fragile and exhibit less vigor.

Environmental factors, including soil type, water availability, and climate, can interact with propagation methods to affect growth and yield. Studies have shown that the success of different propagation methods may vary depending on the local conditions (Franzel *et al.*, 1996). The selection of propagation techniques plays a pivotal role in shaping the growth, productivity, and nutritional content of *Moringa oleifera*. Seed propagation introduces genetic diversity, while vegetative methods such as stem cuttings tend to offer more uniform growth and yield. Additionally, the choice of propagation method can impact the nutritional profile of the plant. Comparative studies and investigations examining the interplay between environmental factors further emphasize the intricacy of this relationship. There is a need for further research to delve into the long-term implications of different propagation methods on both the nutritional quality and yield consistency of *Moringa oleifera*, particularly across diverse geographical and climatic conditions.

2.5. The importance and uses of *Moringa oleifera*

2.5.1. Poverty alleviation

Moringa oleifera plays a pivotal role in poverty alleviation, ensuring food security, and promoting healthcare among various ethnic groups on the continent (Loubelo, 2012). The escalating demand for food to combat hunger and malnutrition has been particularly notable in emerging nations worldwide in recent decades (Saini *et al.*, 2016). Consequently, there's a pressing need to cultivate emerging plants like Moringa. Given these nutritional attributes, Moringa exhibits significant potential as a high-value food crop, medicinal resource, and fodder for livestock, particularly in developing nations (Shahzad *et al.*, 2013).

According to Thapa *et al.* (2019), Moringa's multifunctional uses make it a great choice for small-holder farmers, the rural poor, and marginalized communities looking to better their standard of living. It may be interplanted with a wide variety of other vegetables and has the possibility to boost rural income through job creation, self-sufficiency, and poverty alleviation. Since it can withstand dryness, it needs less fertilizer and manure in addition to less watering. The care of moringa plants doesn't require a lot of work; family members can participate in their free time. The crop shows greater profitability in a short amount of time with less input, especially on limited acreage.

Nearly every part of the tree, including the leaves, flower pods for vegetable purpose, seed oil for cooking, and wood for fuel, is consumed in different ways by people and their animals. By strengthening and supporting rural households and promoting sustainable land use and care, trees can improve nutrition, increase food security, and promote rural development (Popoola and Obembe, 2013; Sivasankari *et al.*, 2014). The leaves are highly nutritious, containing vitamins and minerals, and are utilized fresh, cooked, or as powder (Gandhi, 2018). As highlighted by Marcu (2005), there are no documented adverse effects associated with regular consumption of Moringa leaves. These leaves and seeds are commonly consumed either raw, cooked, or incorporated into food in powdered form for both nutritional and medicinal purposes (Lekgau, 2011). Consequently, Moringa has become a focal point in numerous development initiatives worldwide aimed at alleviating malnutrition, poverty, and mitigating the effects of climate change (Leone *et al.*, 2015). Across various cultures,

Moringa trees have been harnessed to address malnutrition, particularly among infants and lactating women, in numerous developing countries such as India, Pakistan, the Philippines, Hawaii, and various regions of Africa (Jed, 2005; Anwar *et al.*, 2005).

The leaves of the *Moringa oleifera* plant are highly valued as a nutritional supplement to address malnutrition (Fahey, 2005). Numerous studies have demonstrated that *Moringa oleifera* leaves contain a notably high protein content, ranging from 20% to 35% of dry weight. Moreover, the nutritional composition of *Moringa oleifera* leaves is well-balanced, providing all essential amino acids and enriched with unsaturated fatty acids, particularly alpha-linolenic acid, a rare find in plant-based foods (Moyo *et al.*, 2011). In contrast, pods of *Moringa oleifera* are abundant in dietary fiber, low in lipid content, and contain a substantial amount of unsaturated and essential fatty acids, notably oleic acid (Sanchezmachado *et al.*, 2010). Pods and seeds of *Moringa oleifera* offer valuable options for fortification in dairy food products, distinct from the leaves and flowers (Olagbemide *et al.*, 2014). Studies have shown that incorporating *Moringa oleifera* seed powder into wheat flour significantly enhances the protein content of bread and cookies. Additionally, both raw and mature *Moringa oleifera* seeds can be cooked and used as a substitute for beans (Ogunsina *et al.*, 2011).

Moringa oleifera flowers are a rich source of various nutrients, including proteins, potassium, calcium, antioxidants, and polyunsaturated fatty acids, making them suitable for consumption as food or tea and as a dietary supplement after processing (Pontual *et al.*, 2012). When fried, *Moringa oleifera* flowers have been reported to have a taste resembling that of mushrooms (Arise *et al.*, 2014). Traditionally, these flowers are consumed to evoke inspiration and positive energy, contributing to human welfare (Arya *et al.*, 2014). Additionally, they are nectariferous, containing significant amounts of carotenoids (Saini *et al.*, 2014). Extracting a beverage from the flowers has been shown to enhance the quality and quantity of mother's milk. Furthermore, recent findings indicate that *Moringa oleifera* flower powders significantly enhance the nutritional quality of porridge (Funmilayo and Abioye, 2015). Moreover, these flower powders are preferred over leaves as food additives because they do not affect the color or appearance of food.

2.5.2. Medicinal uses of *Moringa oleifera*

Moringa oleifera is revered as a medicinal herb and functional food due to its diverse utility (Abou-Zaid and Nadir, 2014). It offers versatile health benefits and nutritional value. Each part of the plant is rich in essential nutrients, making it valuable for combating malnutrition (Thapa *et al.*, 2019). It offers numerous therapeutic benefits and the ability to treat a wide range of illnesses. Diseases including diabetes, heart disease, anaemia, arthritis, respiratory issues, skin issues, liver issues, paralysis, sterility, rheumatism, digestive disorders, and many more can be treated with it. *Moringa oleifera* has long been recognized as a valuable dietary supplement owing to its remarkable nutritional profile. Renowned as an indigenous source of vitamins, proteins, and minerals, Moringa is esteemed for its digestible proteins, iron, magnesium, calcium, and vitamins B6, B2, and C, as well as carotenoids (Fahey, 2005). Notably, it stands out as one of the richest natural sources of provitamin A (Maheshwari *et al.*, 2014). Additionally, Moringa is rich phytochemicals, which contribute to its medicinal properties (Fahey, 2005). Its nutritional benefits are widely recognized, particularly in regions where access to diverse food sources is limited (Oduro *et al.*, 2008). Every part of the Moringa tree is endowed with a plethora of nutrients. Flowers, leaves, young shoots, and immature pods serve as an excellent source of methionine, phosphorus, calcium, and iron. Notably, all parts of the Moringa plant contain essential nutrients such as proteins, and carbohydrates (Fahey, 2005). Moreover, the leaves and roots are rich sources of natural antioxidants, comprising substantial levels of total phenols, tannins, and flavanols (Muhl *et al.*, 2011). The leaves are particularly noted for their antioxidant properties and amino acid profile, beneficial for immune system support (Anwar *et al.*, 2007).

2.5.3. Socio-economic importance of *Moringa oleifera*

Moringa oleifera emerges as an economical and reliable solution not only for addressing nutritional deficiencies but also for preventing and treating numerous ailments (Paliwal and Sharma, 2011). Its widespread appeal stems from its multifaceted applications and its ability to ensure substantial yields, particularly in regions where populations are highly vulnerable to nutritional inadequacies (Leone *et al.*, 2015). In Africa, indigenous plant species are widely recognized for their significant contribution to the socio-economic equilibrium of local populations, facilitating the

fulfillment of their fundamental requirements. As socio-economic conditions continue to evolve, consumers are increasingly seeking products that offer benefits extending beyond basic nutrition. This trend has led to the rapid expansion of the functional food market globally, representing the fastest-growing segment within the food industry. *Moringa oleifera* emerges as a noteworthy natural food source capable of enhancing the functionality of other foods or serving as a functional food (Sahay *et al.*, 2017). Socioeconomic factors are crucial to every part of farming, regardless of the kind. The agricultural community will not embrace a system unless it is demonstrated to be cost-effective in the context of on-farm circumstances. Polyculture or vertical farming is the only means of sustaining life in such a setting, as the strain on agricultural land is increasing and farm fragmentation will begin very quickly. To meet their food and other needs, people living in rural and urban areas are depending more and more on farm and non-farm income. Farm tree products can be significant revenue generators for farms (Ajayi *et al.*, 2013).

2.5.4. Value added products

The well-known *Moringa oleifera* tree yields leaves, pods, flowers, and seeds that are packed with various nutraceutical compounds and vital nutrients, including vitamins, essential fatty acids, micro and macro elements, and amino acids (Gopalkrishna *et al.*, 2016). This is an opportunity for entrepreneurs to develop a variety of goods with additional value derived from *Moringa oleifera* plant components. They are used for a variety of purposes, including coagulant, gum extraction, fencing, food, medicinal, and fodder (Agoyi *et al.*, 2014; Sivasankari *et al.*, 2014).

Consumers commonly use *Moringa* in a variety of value-added forms. To obtain a higher yield per unit area of land using a precision approach, farmers are now growing *Moringa* as a stand-alone crop, in combination with other agricultural crops grown under organic conditions, or in combination with both organic and inorganic conditions (Sekhar and Vidhyavathi, 2018). The plant's seeds are notable for their use in water purification (Gassenschmidt *et al.*, 1995). *Moringa oleifera* seeds typically contain an oil content ranging from 30% to 42%, and the residue left after oil extraction, known as press-cake, is rich in proteins, including cationic polyelectrolytes with molecular weights between 7 and 17 Daltons, constituting approximately 1% of the total proteins (Foidi *et al.*, 2001). Laboratory analysis has confirmed the presence of these active

coagulants in the press cake even after oil extraction, rendering it suitable to be used as water treatment. Additionally, the press cake can be dried and stored, offering a cost-effective means of obtaining water treatment material as a by-product of oil extraction from Moringa seeds. Therefore, the seeds can initially be used for oil extraction without diminishing their efficacy for water treatment applications. Research has been carried out employing Moringa seeds for the ultimate treatment stage in wastewater treatment systems. Within oxidation lagoons, approximately 80% of the oxygen demand in water is attributed to unicellular algae. These algae also harbor a substantial portion, ranging between 40 to 60% of the nitrogen and phosphorus present in the pre-treated wastewater (Alhassan *et al.*, 2022).

To prevent the eutrophication of rivers or lakes caused by the discharge of high phosphorus and nitrogen loads, Moringa seeds can be utilized to coagulate and remove algae through this process. Typically employed as a natural coagulant, dried seeds are harvested, dehusked, and ground into a powder, which is then mixed with water to form a paste. This paste is added to the water to be treated, allowing it to settle and be filtered, effectively reducing water hardness. As discussed by Pritchard *et al.* (2010), for every litre of water requiring purification, 30 to 300 milligrams of Moringa seed powder are generally adequate. In addition to their coagulation properties, Moringa seeds exhibit antimicrobial characteristics and contain a recombinant protein capable of flocculating both Gram-positive and Gram-negative bacterial cells (Broin *et al.*, 2002).

Moringa seed oil, known as Ben oil, finds application in salad dressings, fine machine lubrication, perfumes, and hair care products (Tsaknis *et al.*, 1999). The seeds are processed into oil for biodiesel and extracted for coagulants (Lijesh and Malhotra, 2016). The press-cake, a by-product, is also rich in protein and used for seasoning (Sahay *et al.*, 2017). According to Mahmood *et al.* (2010), the seeds were utilized by the Romans, Greeks, and Egyptians to extract edible oil, which was then used for skin lotion and scent. The oil extracted from Moringa plantations in the West Indies was shipped to Europe in the 19th century to be used in machinery lubricants and perfumes.

The seed cake derived from processing Moringa seeds to extract oil serves as a valuable source of fertilizer, despite being inedible due to its content of harmful substances. Nevertheless, it boasts high protein levels, rendering it beneficial for

agricultural use (Muyibi and Evison, 1995). Additionally, the Moringa refined seed oil is regarded as a viable alternative to olive oil due to its rich content of essential fatty acids, surpassing even soybean oil in lipid composition, thus rendering it nutritionally significant (Morton, 1991). Furthermore, the seeds boast a high concentration of essential amino acids, making them an excellent substitute for legumes, particularly given their superior content of sulfur-containing amino acids (Ferreira *et al.*, 2008).

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Description of the study area

The experiment was conducted at the University of Limpopo Aquaculture Research Unit (ARU), located in Mankweng area, Limpopo Province, South Africa (23°53'10"S, 29°44'15"E) at an elevation of 1320 m above sea-level. Furthermore, the area experiences average temperatures that ranges between 28 to 30°C in summer and 13 to 15°C in winter. The site is characterized by loamy sand as indicated under Table 4.1. The area is semi-arid, and it experiences erratic low rainfall which ranges between 450-650 mm per annum. A meteorological station placed at 30 meters from the experimental area provided the data on average rainfall and temperature (Figure 3.1).

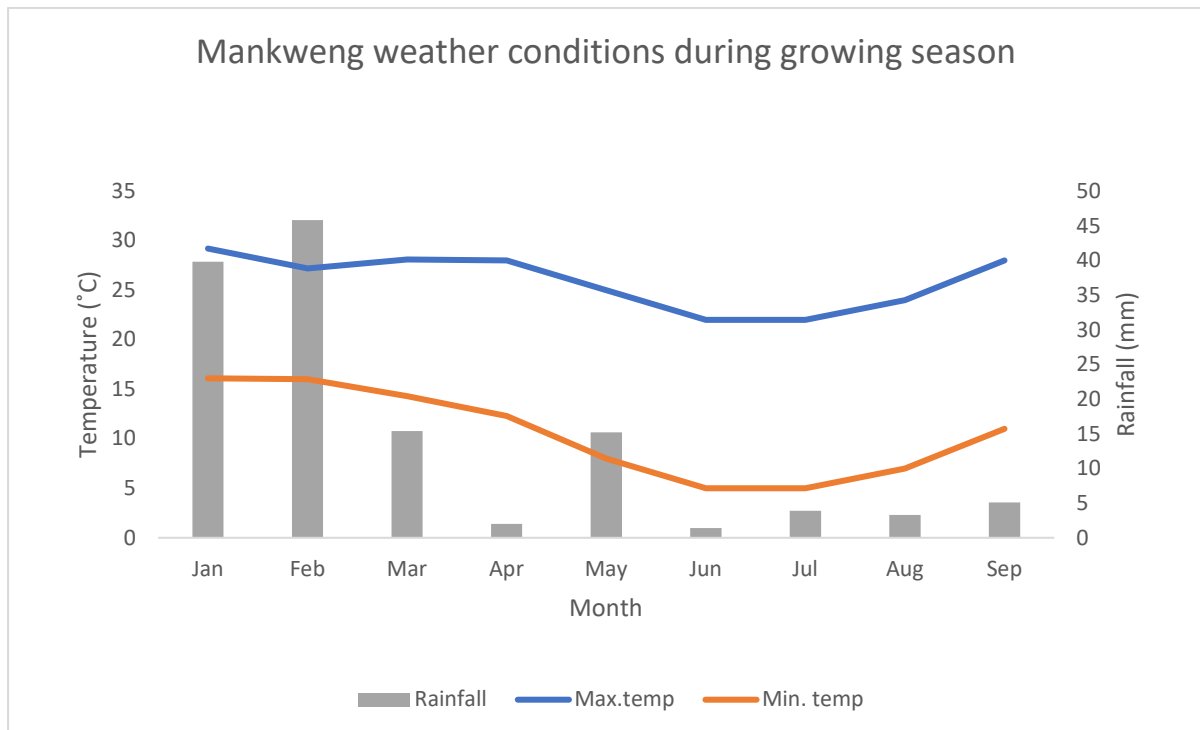


Figure 3.1: Monthly rainfall, minimum and maximum temperatures during 2023 growing season.

3.2. Experimental design and treatments

A pot experiment was designed in a randomized complete block design (RCBD), consisting of three treatments (direct seeding (T1), seedlings (T2), and stem cuttings (T3) as propagation methods each replicated six times (Figure 3.2). Direct seedling propagation method was used as control treatment. Each treatment was planted in two polythene bags and each replication consisted of six planting bags.

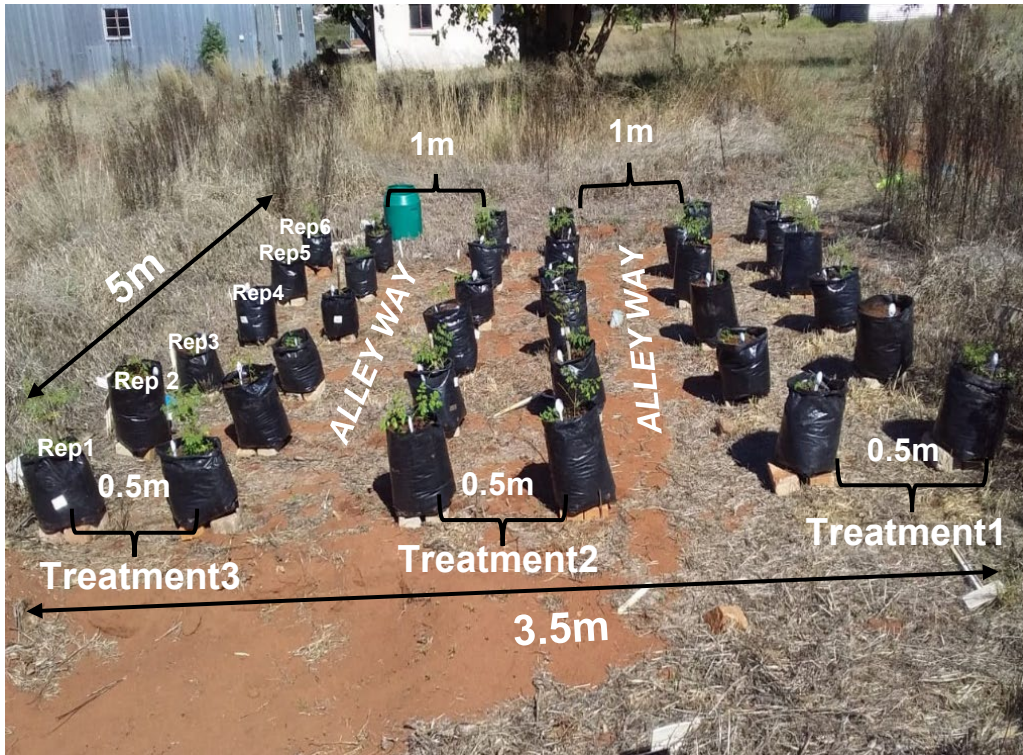


Figure 3.2: The layout of the treatments at Aquaculture Research Unit

3.3. Planting procedures

A dedicated shadehouse area was set up to raise Moringa seedlings for transplanting. It provided optimal conditions for seed germination and seedling growth, including controlled temperature, humidity, and adequate sunlight exposure. Regular monitoring and maintenance were carried out to ensure the health and vigor of the seedlings. Prior to planting, the soil in the planting area was assessed for its physical and chemical properties. Any amendments required to improve soil fertility and structure were made accordingly. The most common propagation methods for Moringa, namely direct seeding, transplanting, and stem cuttings, were chosen based on factors such as availability of planting material and experimental objectives. Each method was carefully considered to maximize plant survival and growth under the experimental conditions.

3.3.1. Planting preparations

A fairly-level portion of an area measuring 5 m length and 3.5 m breadth was cleared of weed trash using a grass mower and roundup used to control weeds. The planting was done in polythene bags of 30 cm in height and 90 cm in circumference. For this experiment, 36 polythene bags were used. The polythene bags were prefilled with

topsoil collected from the Aquaculture Research Unit. In each treatment, two planting bags were placed at 50 cm apart and the spacing between treatments were fixed at 1 m and each pot was put on top of two paver bricks. Moringa was then propagated according to the treatments through direct seeding, transplanting, and stem cuttings.

3.3.2. Soil sampling and analysis

A composite soil sample was collected from the top 0 to 15 cm layer before planting. This sample was then dried in an oven at 105°C for 48 hours prior to analysis. The remaining soil was air dried and passed through a 2 mm sieve for further testing. The following analyses were conducted: pH and electrical conductivity (EC) using electronic methods; NH₄-N and NO₃-N levels using colorimetric techniques; Available phosphorus determined through the Bray 1 extraction method (1995); and particle size distribution assessed via the hydrometer method.

3.3.3. Direct seeding (Treatment 1)

Mature seeds of *Moringa oleifera* were randomly collected from well-developed pods of a healthy and productive mother tree located at the University of Limpopo Experimental Farm, Syferkuil. Healthy and non-insect damaged seeds were selected for planting. Seeds were soaked for 24 hours in tap water before sowing to allow the seeds to imbibe water for sprouting. Three seeds were directly sown into the polythene bags at 2 cm maximum depth. Thinning was done to remove weak seedlings to target the only one healthy and vigorous seedling in each pot. The process of thinning was done after watering the seedlings for easy uprooting.

3.3.4. Transplanting (Treatment 2)

Seedlings were grown in plastic bags prefilled with propagation mix by sowing two seeds per plastic bag at 2 cm depth and watering with 10 to 15 ml of water per seedling once every two to three days in a shade house. One week after emergence, the seedlings were thinned to the strongest seedling. The Moringa seedlings were nursed for 8 weeks before transplanting for a better survival rate when they are about 15 to 30 cm in height. The seedlings were later transplanted two months after sowing into polythene bags filled with topsoil. Multi Booster water soluble fertilizer for fertigation with magnesium enriched which contains the active ingredient of 112 g/kg N, 52 g/kg P, 264 g/kg K, and 19 g/kg Mg was applied at the time of transplanting and the newly transplanted trees were irrigated immediately after transplanting to promote early root

development. The survival of transplanted seedlings was monitored daily to see if there was any mortality until they had properly recovered and well established.

3.3.5. Stem cuttings (Treatment 3)

Stem cuttings were collected from the existing and actively growing mother plants at the University of Limpopo Experimental Farm, Syferkuil. Clones were harvested from branches of a tree which has developed hardwood and thus, young green stem tissue were avoided. The cuttings were specifically prepared by considering the position and direction of cup-like nodes. The cuttings were cut to a length of about 45 cm long. Tip portions of the shoots were discarded, and the leaves of the cuttings were trimmed to induce sprouting. Cuttings having 2-3 nodes were prepared by taking the horizontal cut at the apex and slanting cut at the base.

3.3.6. Cultural practices

Fresh water was supplied every morning to avoid wilting and for normal plant development. Other seedling management was fertigated with multi-booster fertilizer at 32 g/2000 ml water to provide nitrogen (N), phosphorus (P), and potassium (K) nutrients in a balanced and appropriate manner for the seedlings to promote growth. This concentration ensures that the fertilizer is sufficiently diluted for safe application without causing nutrient burn or stress to the seedlings. Weeding was done manually by hand in all treatments to control competition of water and nutrients. The soil in the pots was often loosened using a fork to promote soil aeration and infiltration and to avoid compaction.

3.4. Data collection

Data for plant growth and yield variables was collected six months after planting. The following growth, yield parameters and nutritional composition were recorded.

3.4.1. Emergence, sprouting rates.

Emergence and sprouting rates for seed and cutting propagation percentage was calculated to evaluate emergence percentage. Emergence percentage for seedlings in a shade house were recorded two weeks after planting by counting the number of seedlings that have emerged from each pot and for direct seeding treatment were calculated two weeks after planting. The number of successfully sprouted cuttings were recorded and calculated as a percentage of the total.

The emergence percentage for direct seeding and transplanting treatments was calculated using the following formula:

$$\text{Emergence percentage (\%)} = \frac{\text{Number of plants emerged}}{\text{Number of seeds sown}} \times 100 \quad (\text{Equation 1})$$

The sprouting percentage for stem cutting treatments was calculated using the following formula:

$$\text{Sprouting percentage (\%)} = \frac{\text{number of sprouted cuttings}}{\text{number of cuttings planted}} \times 100 \quad (\text{Equation 2})$$

3.4.2. Plant height (cm)

The plant height in each treatment was measured to estimate the average height of the plants. Average height of the plants was estimated by measuring heights of two different plants in each plot of each treatment. The measurements for direct seeding and transplanting treatments were taken using a measuring tape from the soil surface at the plant's base to the highest point on the leaves. Plant height for cutting propagation was measured from the base of the cutting to the highest point of the plant's shoot.

3.4.3. Number of branches per plant

The number of branches were determined by conducting a systematic count of primary branches from two representative plants within each experimental plot, precisely at the 8-week mark post-planting.

3.4.4. Stem diameter (mm)

The stem diameter was measured on two plants per pot at eight weeks after planting using an electronic digital vernier caliper at a height of 3 cm above the ground for seed propagation and cutting to maintain consistency in the data collection.

3.4.5. Chlorophyll content determination (CCI)

The chlorophyll content, measured as the chlorophyll index, was assessed using a handheld chlorophyll content meter. Fully expanded outer and top leaves from random selections within the tree canopy were chosen for measurement every three weeks. The chlorophyll content index was calculated as the average of the two measurements obtained for each leaf.

3.4.6. Fresh and dry matter of the shoots

Harvesting in all the treatments was done at 28 weeks after trial establishment to determine biomass production. The shoots and roots were carefully separated manually from each other. Each component (shoots and roots) was individually weighed immediately after harvesting using an electronic weighing balance to determine their fresh biomass. Samples were then placed in an oven with forced air circulation at 60 °C until constant weight. Afterwards, the samples were weighed again to determine the dry matter weight.

3.4.7. Nutritional composition

Dried Moringa leaves were analysed for nutritional composition at 28 weeks after planting. This was done to assess whether there are any significant differences in the nutrient content of Moringa leaves among plants propagated by different methods. The leaves from each treatment were washed thoroughly to remove dust and any unwanted materials. Fresh and matured leaves were harvested by detaching them from the stem. Leaf samples collected based on various treatments were subjected to drying in an oven at 45°C for 72 hours, followed by grinding to pass through a 2 mm sieve. Ten grams of the resulting fine fraction were used for determining the chemical composition of Moringa leaves. The fat content was assessed using ether extraction in the Tacator Soxtec (HT6) System (1999), procedure 920.39. Ash content was determined by combusting the samples overnight at 550°C in a muffle furnace, followed by cooling in a desiccator, as per method 968.08 of the Association of Official Analytical Chemists (AOAC) (2000). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined using an ANKOM 220 fibre analyser, following the method of Van Soest *et al.* (1991). The concentration of phosphorus (P) was measured using an auto-analyser (Allen *et al.*, 1974). Mineral compositions were analysed according to AOAC (2000) methods. Calcium (Ca), potassium (K), sodium (Na), and magnesium (Mg) were analysed following AOAC methods 910.01, 956.01, 929.03, and 920.09, respectively. Micronutrient's zinc (Zn), copper (Cu), iron (Fe), and manganese (Mn) were analysed using AOAC methods 941.03, 953.03, 937.03, and 921.02, respectively. The three macronutrients Ca, Mg, and K were expressed as a percentage of dry matter, and the cation ratio K/ (Ca + Mg) was calculated based on a mole equivalent basis.

3.5. Data analysis

The data collected were subjected to analysis of variance using Genstat 18th Edition to determine the effect of different propagation methods on measured variables. Where significant F-values from the treatment effect were found, means were separated by the least significant difference (LSD) at a probability level of 0.05.

CHAPTER 4: RESULTS

4.1. Pre soil physical and chemical properties for the experimental site

The soil physical and chemical properties of the soil for the experimental site are shown in Table 4.1. The soil was loamy sand with a very high sand percentage (84%) which was attributed to high organic carbon (1.44%) and low to moderate electrical conductivity (255 $\mu\text{S}/\text{cm}$). It was more alkaline with a pH of 7.62 and had a level that was within the measured range of available phosphorus (4.910 mg/kg) for optimal plant growth. The soil had a high level (1,764 mg/kg) of ammonium nitrogen compared to nitrate nitrogen ($\text{NO}_3\text{-N}$) which resulted in low levels (0.009 mg/kg).

Table 4.1: Physical and chemical properties of the soil

Physical properties	Value
Particle size distribution (%)	
Sand	84
Silt	10
Clay	6
Texture class	Loamy Sand
Chemical properties	
pH in H_2O	7.62
EC ($\mu\text{S}/\text{cm}$)	255
Organic Carbon (%)	1.44
Phosphorus (mg/kg)	4.910
$\text{NH}_4\text{-N}$ (mg/kg)	1,764
$\text{NO}_3\text{-N}$ (mg/kg)	0,009

4.2. Effect of different propagation methods on *Moringa oleifera* emergence percentage

Figure 4.1 below shows the emergence percentage of the three propagation methods used to raise *Moringa oleifera* seedlings. Emergence from the seedling transplanting treatment spanned from the 7th to the 10th day after planting. The emergence of sprouts in stem cuttings occurred between the 12th day and 13th days after planting, while the emergence of seedlings from the direct seeding treatment ranged from the 12th to the 14th day after planting. There was no significant difference among all treatments at day

7 and day 14 after planting, however, from day 8 to day 10 after planting, seedling transplanting differed significantly ($p < 0.001$) compared to both direct seeding and stem cuttings methods of propagation. Direct seeding was the least successful propagation technique, with a 22.2% emergence percentage 12 days after planting; in comparison, stem cuttings produced an emerging percentage of 91.67%, while seedling transplantation produced a 100% emergence percentage 12 days after planting.

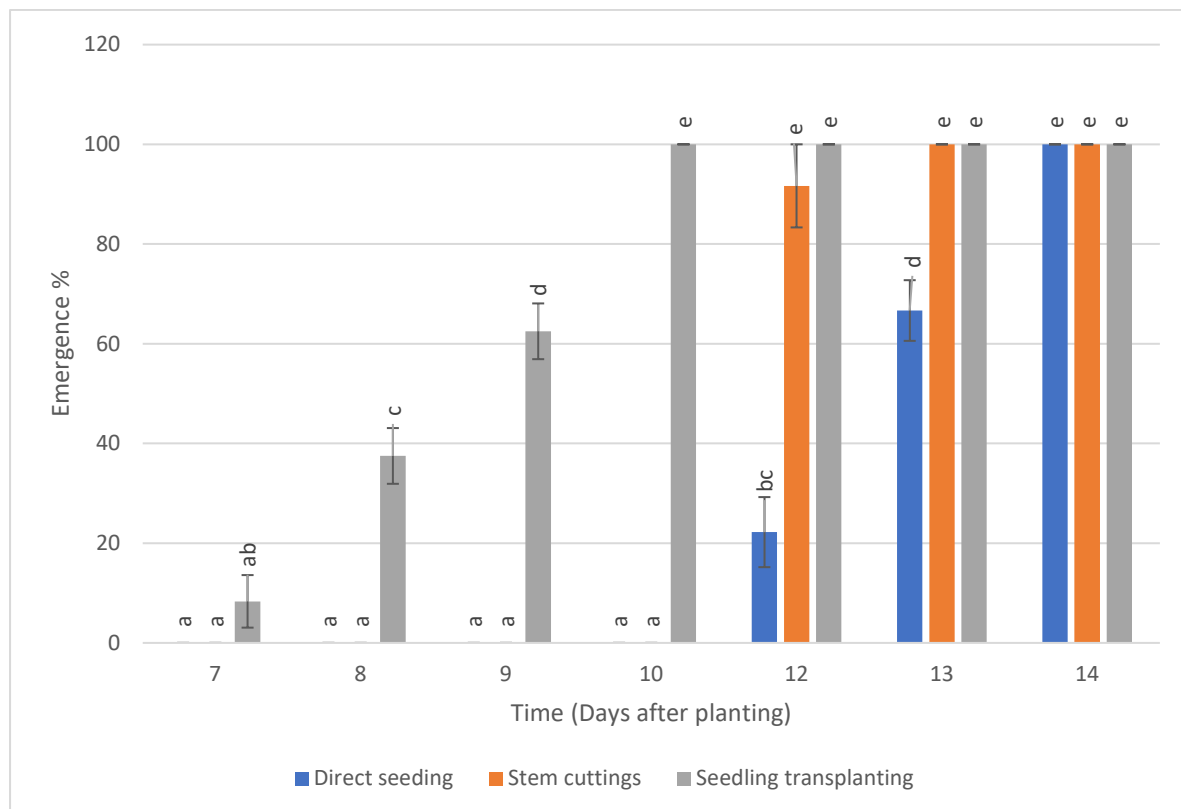


Figure 4.1: Daily emergence rate of *Moringa oleifera* influenced by the different methods of propagation. Means with different letters differ significantly ($p \leq 0.05$).

4.3. Effect of different propagation methods on *Moringa oleifera* plant height

The plant height of the three propagation methods (direct seeding, stem cuttings, and seedling transplanting) used to raise *Moringa oleifera* seedlings is indicated in Figure 4.2. At 13 weeks after planting, stem cuttings differed significantly with a p value that is less than 0.001 compared to direct seeding. At 14 weeks after planting, there was a significant difference ($p < 0.001$) in direct seeding compared to both stem cuttings and seedling transplanting. Seedling transplanting produced taller plants, with an average height of 42.21 cm at 28-weeks after planting. In the case of stem cuttings, the plants

reached an average height of 39.79 cm within 28 weeks. Direct seeding resulted in plants exhibiting the lowest mean height, measuring at 21 cm after 28 weeks of growth.

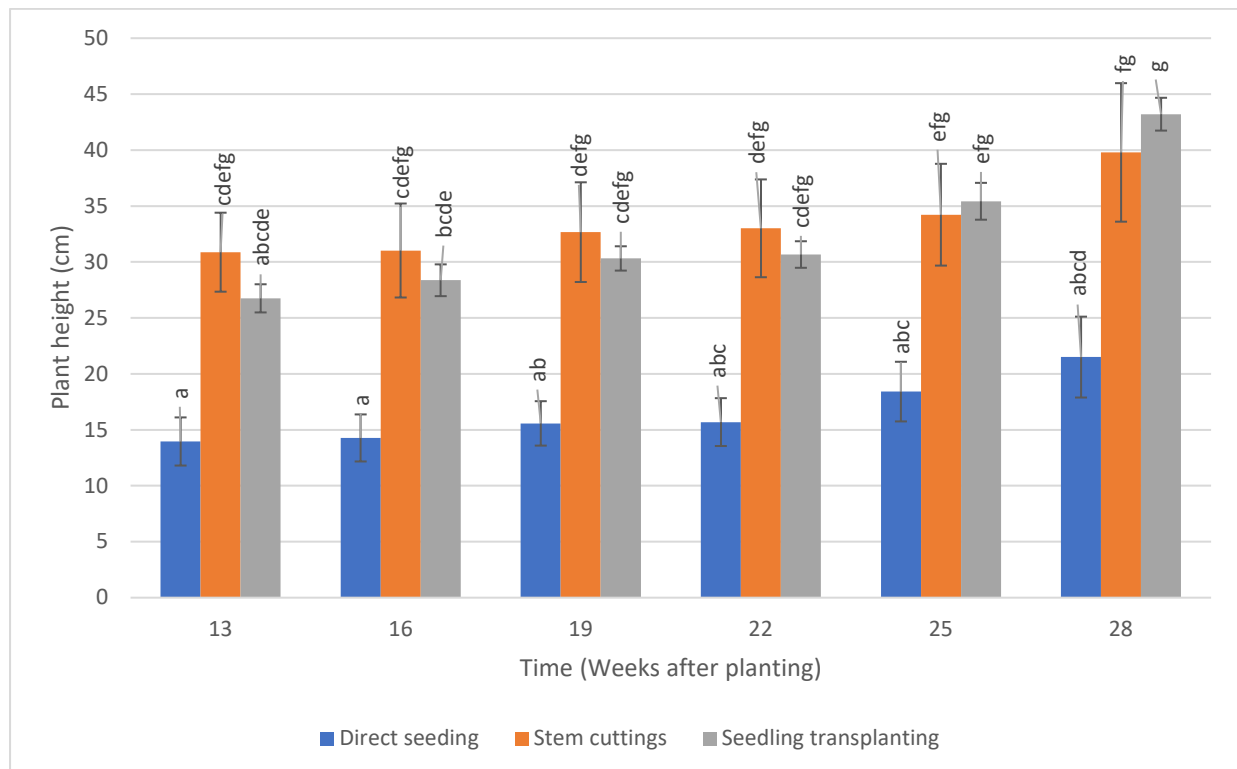


Figure 4. 2: Plant height of seedlings influenced by propagation methods. Means with different letters differ significantly ($p \leq 0.05$).

4.4. Effect of different propagation methods on number of branches per plant

The number of branches per plant of the three propagation methods used to raise *Moringa oleifera* seedlings is depicted in Figure 4.3. The results revealed distinct differences in the number of branches among the three propagation methods. At 28 weeks after planting, the number of branches per plant differed significantly ($p < 0.001$) among all the treatments. *Moringa oleifera* plants propagated through direct seeding exhibited an average of 10 branches per plant, while seedling transplanting resulted in *Moringa oleifera* plants with a notably higher average of 17 branches per plant at 28 weeks after planting and in the case of stem cuttings, plants exhibited the lowest average number of branches, with just 3 branches per plant.

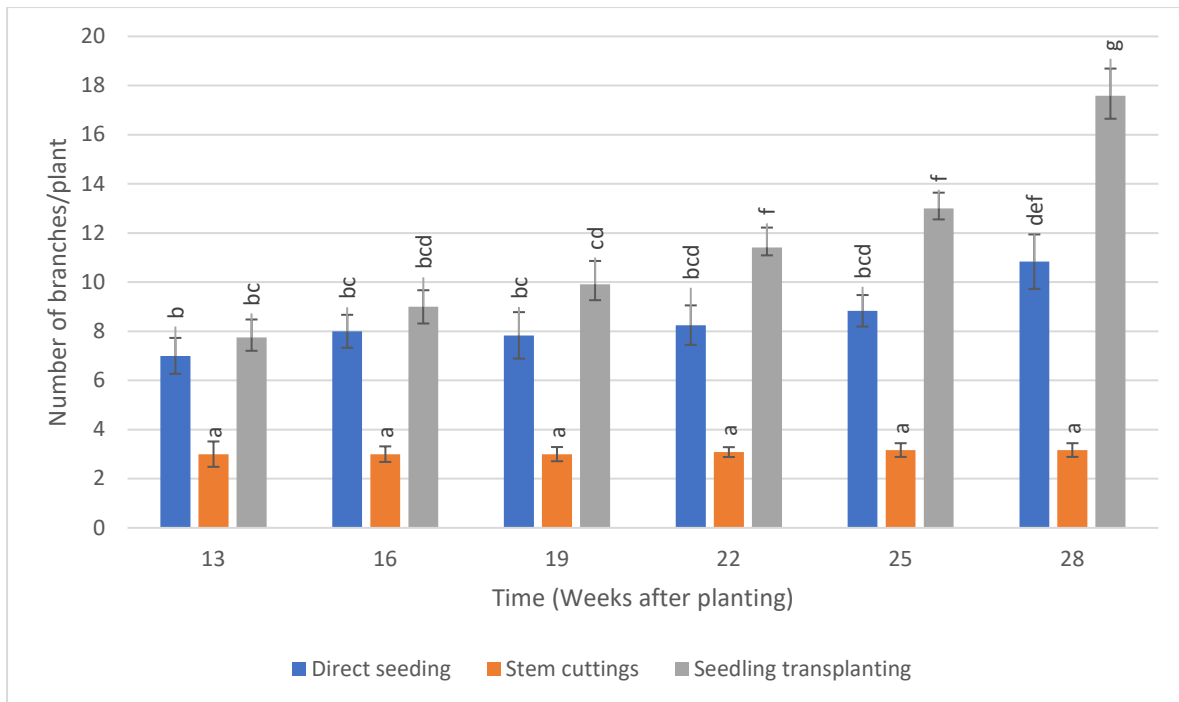


Figure 4.3: The number of branches per plant influenced by different methods of propagation. Means with different letters differ significantly ($p \leq 0.05$).

4.5. Effect of different propagation methods on stem diameter of *Moringa oleifera*.

The stem diameter of the three propagation methods used to raise *Moringa* seedlings is indicated in Figure 4.4. The results revealed distinct differences in stem diameter among the various propagation methods. At 28 weeks after planting, the stem diameter differed highly among all the treatments. *Moringa oleifera* plants propagated through direct seeding exhibited an average stem diameter of 5.65 mm at 28 days after planting. Seedling transplanting resulted in plants with a notably larger average stem diameter of 10.74 mm at 28 days after planting. In the case of stem cuttings, *Moringa* plants exhibited an average stem diameter of 7.02 mm at 28 days after planting.

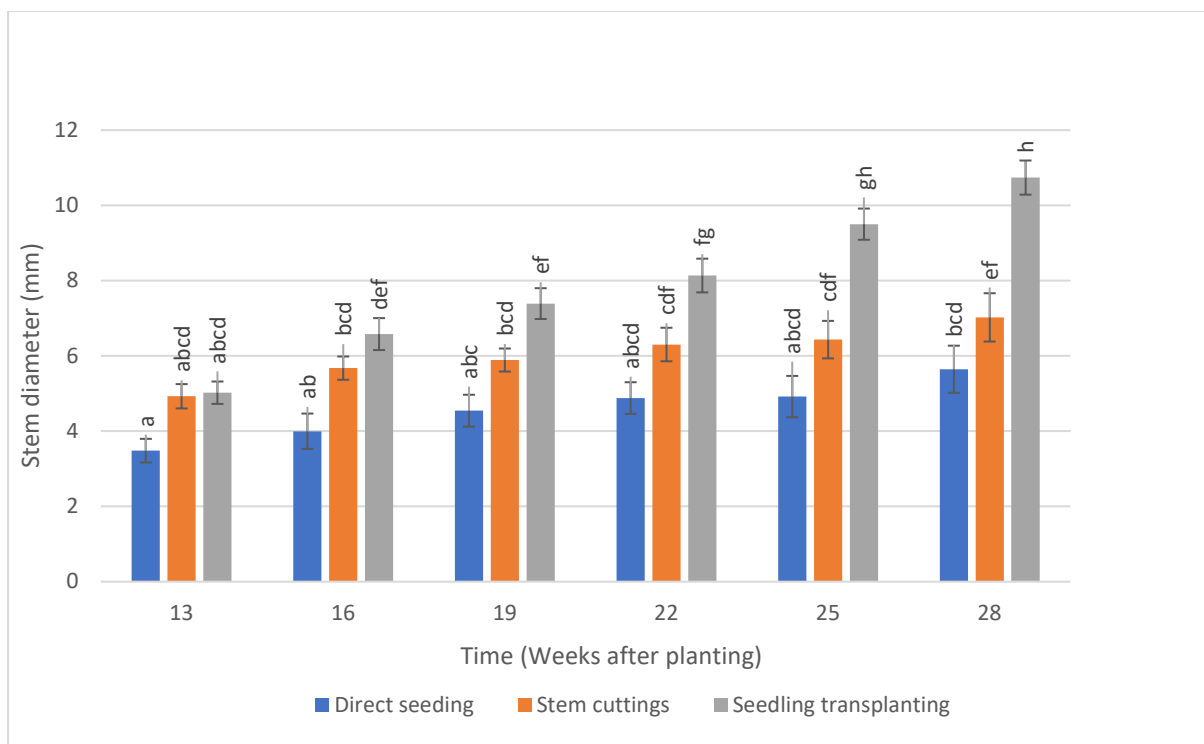


Figure 4.4: The stem diameter influenced by methods of propagation. Means with different letters differ significantly ($p \leq 0.05$).

4.6. Effect of different propagation methods on the chlorophyll content of *Moringa oleifera*

Significant differences were observed between the means of the three tested propagation methods. *Moringa* plants propagated through direct seeding displayed a trend of chlorophyll content increase throughout the growing period, but this increase was not statistically significant as shown in Figure 4.5 below. The chlorophyll content in stem cuttings did not differ significantly from the earlier stages. In contrast, the *Moringa oleifera* plants propagated through seedling transplanting exhibited a different trend. Chlorophyll content in this method was highly significant ($p < 0.001$) at 28 weeks after planting compared to direct seeding and stem cuttings. Plants propagated through direct seeding exhibited the lowest chlorophyll content, with an average chlorophyll concentration of 15.17 CCI at 28 days after planting. Seedling transplanting resulted in a notably higher average chlorophyll content of 45.18 CCI and in the case of stem cuttings, the lowest average chlorophyll content of 12.65 CCI at 28 days after planting.

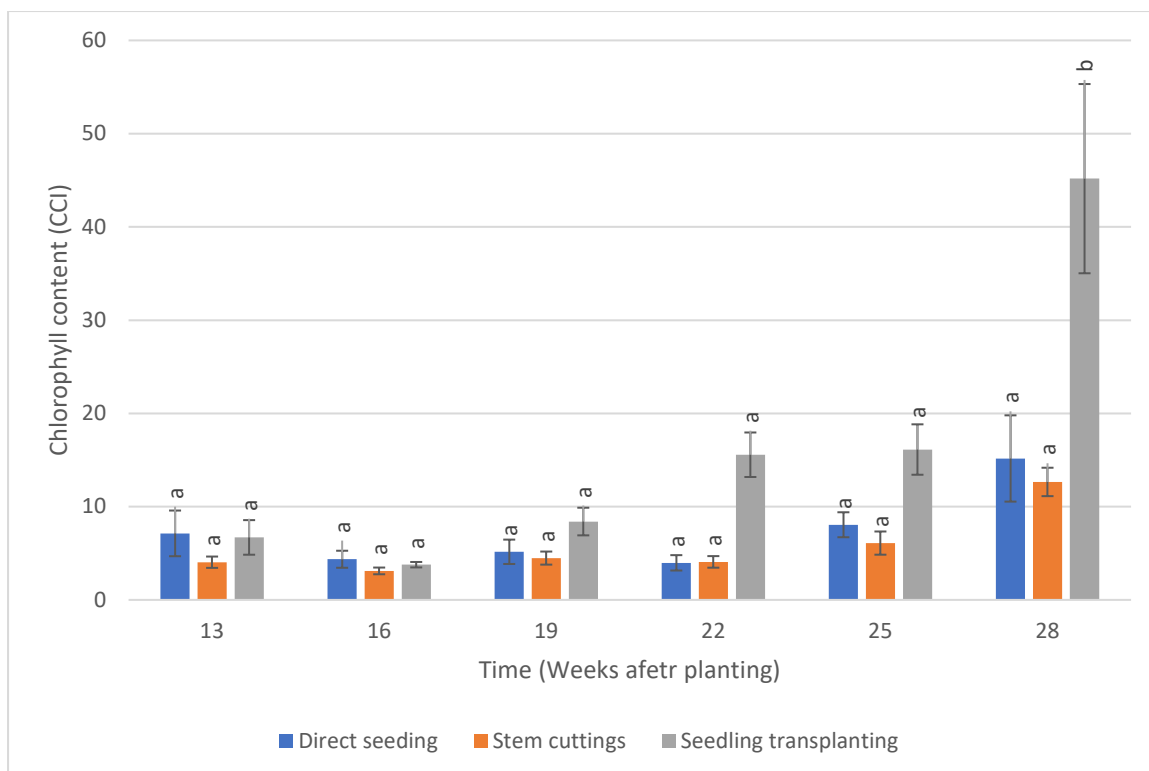


Figure 4.5: The chlorophyll content influenced by methods of propagation. Means with different letters differ significantly ($p \leq 0.05$).

4.7. Effect of different propagation methods on the fresh and dry shoot weight of *Moringa oleifera*

The fresh and dry shoot weights of *Moringa* seedlings propagated through three different methods are presented in Figure 4.6. Statistical analysis revealed that stem cuttings did not show significant differences in shoot weights compared to seedling transplanting. However, direct seeding resulted in significantly different shoot weights compared to the other methods. Specifically, plants propagated through direct seeding exhibited the lowest shoot weights, with an average of 6.73 g for fresh shoot weight and 2.02 g for dry shoot weight at 28 days after planting. Seedling transplanting yielded plants with notably higher average shoot weights, measuring 26.30 grams for fresh shoot weight and 7.45 grams for dry shoot weight. Stem cuttings produced plants with an average fresh shoot weight of 19.47 grams and an average dry shoot weight of 6.46 grams at 28 days after planting.

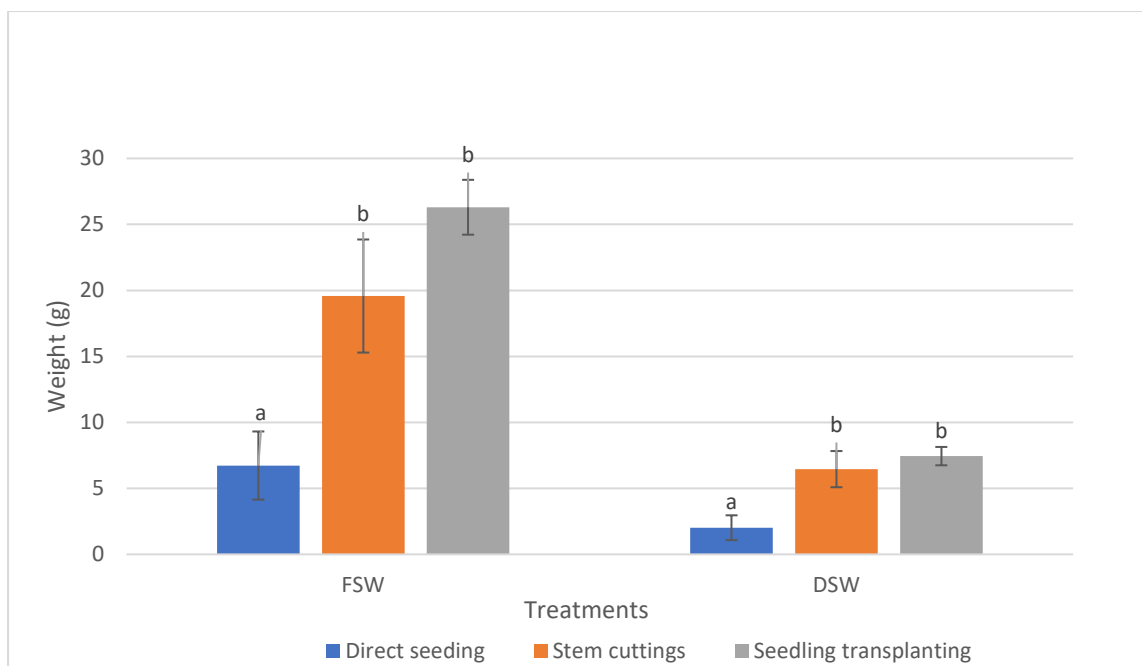


Figure 4.6: Moringa biomass production as influenced by the methods of propagation. Means with different letters differ significantly ($p \leq 0.05$). FSW = Fresh shoot weight and DSW= Dry shoot weight

4.8. Effect of different propagation methods on the fresh and dry root weight of *Moringa oleifera*

The fresh and dry root weights of Moringa seedlings propagated through three different methods are depicted in Figure 4.7. Statistical analysis indicated that seedling transplanting resulted in significantly higher root weights at 28 weeks after planting compared to both direct seeding and stem cuttings. However, there was no significant difference in root weights between direct seeding and stem cuttings methods of propagation. Plants propagated through direct seeding displayed the lowest root weights, with an average of 19.51 g for fresh root weight and 4.31 g for dry root weight at 28 days after planting. Seedling transplanting yielded plants with higher average root weights, measuring 67.24 g for fresh root weight and 16.23 g for dry root weight. Stem cuttings produced plants with an average fresh root weight of 35.19 g and an average dry root weight of 6.46 g at 28 days after planting.

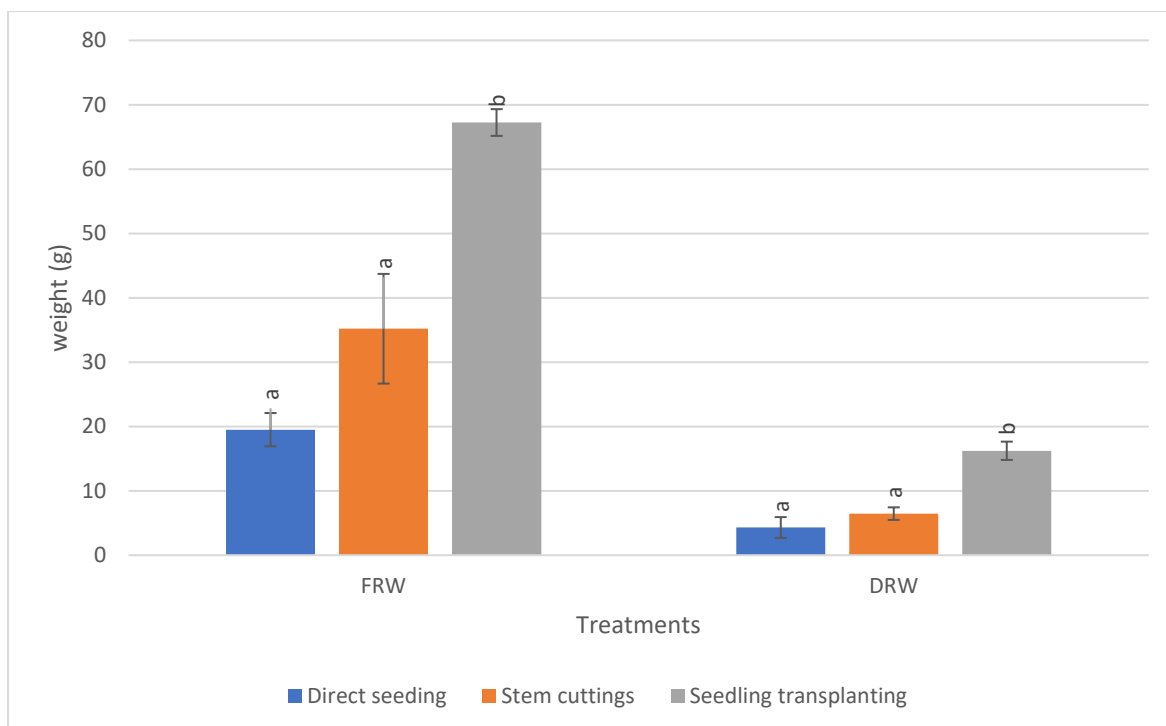


Figure 4.7: The fresh root weight (FRW) and dry root weight (DRW) of *Moringa* influenced by the methods of propagation. Means with different letters differ significantly ($p \leq 0.05$).

4.9. Effect of different propagation methods on micronutrients' content of the *Moringa oleifera* leaves

Data on micronutrient element evaluation is presented in Table 4.2 below. *Moringa* plants propagated through stem cuttings exhibited a notable increase in the iron (Fe) content of leaves, showing a higher average of 775.50 ppm compared to those raised through direct seeding and seedling transplanting. There was a significant difference in Iron (Fe) between the propagation methods with a p value that is less than 0.001, however, the direct seeding resulted in a high average concentration of 360 ppm, compared to seedling transplanting with an average of 231.50 ppm. There were significant differences in Manganese (Mn) concentration observed among all the three methods of propagation ($p < 0.001$). Direct seeding resulted in higher Manganese (Mn) concentration of 61.50 ppm compared to stem cuttings and seedling transplanting which both resulted in an average of 44 ppm concentration. Statistical analysis confirmed that there were significant differences in the concentrations of Copper (Cu) among all the three methods of propagation used with a p value that is less than 0.001. The Copper (Cu) concentration from all the treatments ranged from 1.5 to 4.50 ppm.

The Zinc (Zn) concentration of Moringa leaves from direct seeding showed significant difference ($p < 0.001$) from seedling transplanting which ranged from 10 to 15.50 ppm. In the case of stem cuttings, the Zinc content in Moringa leaves showed a high significant difference compared to other methods with an average of 26.50 ppm.

Table 4.1: The effect of methods of propagation on micronutrients of *Moringa oleifera* leaves

Treatments	Fe	Mn	Cu	Zn
Direct seeding	360 ^b	61.50 ^b	4.50 ^b	15.50 ^b
Stem cuttings	775.50 ^c	44 ^a	4.50 ^b	26.50 ^c
Seeding transplanting	231.50 ^a	44 ^a	1.50 ^b	10 ^a
<i>p-value</i>	0.001	0.001	0.001	0.001
<i>Cv%</i>	2.6	9.3	10.4	11.2

*Mean values. ^{a-h} means in same column but with different superscripts differ significantly ($p \leq 0.05$). Fe= Iron Mn= Manganese Cu= Copper Zn= Zinc

4.10. Effect of different propagation methods on the macronutrients' content of *Moringa oleifera*

The macro-nutrient element evaluation of the three propagation methods was conducted and the findings are presented in Table 4.3 below. There were no significant differences in Calcium (Ca), Potassium (K), Magnesium (Mg), Sodium (Na), Phosphorus (P), and the K/Ca+Mg ratio among all the three propagation methods which resulted in an average that ranged from 1 to 2.50 %. Calcium (Ca) resulted in an average content that ranged from 1.03 to 1.36% for all the treatments. Moringa leaves' Potassium (K) content differed significantly in direct seeding ($p < 0.001$) compared to other methods with a range of 2.03 to 2.37%.

Table 4.2: The effect of propagation methods on the macronutrients of Moringa leaves

Treatments	Ca	K	Mg	Na	P	K/Ca+Mg
Direct seeding	1.36 ^b	2.37 ^b	0.42 ^a	0.12 ^a	0.35 ^a	0.59 ^a
Stem cuttings	1.03 ^a	2.03 ^a	0.46 ^a	0.11 ^a	0.39 ^a	0.59 ^a
Seedling transplanting	1.11 ^{ab}	2.05 ^a	0.33 ^a	0.12 ^a	0.39 ^a	0.67 ^a
<i>p-value</i>	0.012	0.001	0.244	0.815	0.283	0.310
<i>Cv%</i>	13.5	0.9	32.3	23.3	12.5	15.6

*Mean values. ^{a-h} means in same column but with different superscripts differ significantly ($p \leq 0.05$).

Ca= Calcium K= Potassium Mg= Magnesium Na= Sodium P= Phosphorus

4.11. Effect of different propagation methods on the proximate composition of *Moringa oleifera*.

The proximate composition results are shown in Table 4.4 below. Stem cuttings resulted in significantly higher ADF, NDF, and ash content compared to both direct seeding and seedling transplanting. However, there were no significant differences in ADF, NDF, and ash content among all methods of propagation.

The Fat content in *Moringa oleifera* leaves significantly varied between the propagation methods ($p < 0.001$). Direct seeding demonstrated the highest Fat content, averaging 7.58%. Conversely, stem cuttings and seedling transplanting did not exhibit significant differences in Fat content. Notably, seedling transplanting presented a higher average Fat content of 6.76% compared to stem cuttings, which displayed a lower Fat content of 5.41%.

Regarding Protein content, seedling transplanting showed a highly significant difference ($p < 0.001$) compared to other propagation methods, with an average of 30.75%. There were no significant differences in Protein content between stem cuttings and direct seeding. However, direct seeding displayed a higher average Protein content of 29.36% compared to stem cuttings, which exhibited a lower average Protein content of 25.79%.

Table 3.4: The effect of different propagation methods on the proximate composition of Moringa leaves.

Treatments	ADF	NDF	Fat	Protein	Ash
Direct seeding	12.75 ^a	20.45 ^a	7.58 ^c	29.36 ^b	11.43 ^a
Stem cuttings	16.06 ^b	22.58 ^a	5.41 ^a	25.79 ^a	13.22 ^b
Seeding transplanting	12.37 ^a	20.38 ^a	6.76 ^b	30.75 ^c	10.71 ^a
<i>p-value</i>	0.001	0.270	0.001	0.001	0.001
<i>Cv%</i>	7.3	11.8	5.2	2.7	5.0

*Mean values. ^{a-h} means in same column but with different superscripts differ significantly ($p \leq 0.05$).

ADF= Acid Detergent Fibre and NDF= Neutral Detergent Fibre

CHAPTER 5: DISCUSSION

5.1. The soil physicochemical properties of the experimental site

The soil physicochemical properties described for the experimental site suggest favorable conditions for *Moringa oleifera* production, despite a few considerations. The soil texture was loamy sand with 84% sand proportion, which promotes excellent drainage and aeration, crucial for root development and nutrient uptake in plants (Brady and Weil, 2008). Additionally, the soil resulted in a substantial organic carbon content of 1.44%, indicative of good fertility and microbial activity, both beneficial for overall plant vigor (Lehmann and Kleber, 2015). However, the soil registered a pH of 7.62, indicating slightly alkaline conditions. While *Moringa oleifera* typically thrives in neutral to slightly acidic soils, it is known to tolerate a broader pH range (Morton, 1991; Tshabalala *et al.*, 2020). Furthermore, the available phosphorus level of 4.910 mg/kg falls within the optimal range required for plant growth (Khan *et al.*, 2018). Phosphorus is crucial for root development, flowering, and fruiting in plants, including *Moringa oleifera*, thereby ensuring adequate nutrient availability despite the alkaline pH. *Moringa oleifera* possesses efficient nitrogen-fixing capabilities and can utilize ammonium effectively for growth (Morton, 1991). Optimum level of electric conductivity in the soil ranges from 200-1200 $\mu\text{S}/\text{cm}$. The moderate electrical conductivity of 255 $\mu\text{S}/\text{cm}$ indicates relatively low salinity, which is favorable as high salinity can hinder plant growth (Afrin *et al.*, 2020).

5.2. The effect of propagation methods on the emergence percentage of Moringa plant

In this study, seedling emergence was observed to be significantly influenced by the by the choice of propagation method at the probability level that is less than 0.001, with various factors, including weather conditions, contributing to this influence (see Figure 4.1). For instance, the method of seedling transplanting exhibited a distinct influence on seedling emergence compared to alternative methods. This significant difference ($p < 0.001$) suggests that factors associated with seedling transplanting, such as the timing of transplantation, soil preparation techniques, and shade house management practices, played a critical role in influencing seedling emergence outcomes.

The high emergence percentage suggests that this method is highly effective in ensuring the survival and growth of Moringa seedlings. While it may require more initial resources and effort, the results demonstrate its suitability when environmental conditions are less favorable or when precise control over seedling development is essential. Additionally, environmental factors such as temperature, humidity, and precipitation patterns likely interacted with the transplanting process, influencing seedling establishment and growth rates. This agrees with the findings of Oni and Ojo, (2002) that most seeds are generally viable except for those with impermeable seed coats and have the capacity to absorb enough water for their germination from the soil at field capacity.

The findings of this study align with those of Bosch (2014), indicating that Moringa germination typically occurs within 7 to 14 days after sowing. Korsor *et al.* (2016) suggested that the early germination of Moringa seeds may be attributed to their quality. Additionally, it was observed that on the 11th day, there was a higher number of emerging seedlings of Moringa in polythene bags. This finding is consistent with a study conducted in Malawi, which reported that viable seeds of Moringa germinate within two weeks (Nalivate *et al.*, 2011). Fuglie and Sreeja (2001) found that germination occurred between the 5th and 12th days after sowing, with the duration influenced by the age of the seed. Furthermore, Cangré Ebou and Frédéric (2022) discovered that the germination window of *Moringa oleifera* typically spans 7.5 ± 1.29 days, with an average germination delay of 6 days, and this timing is not influenced by the sowing medium or seed age ($p > 0.05$).

5.3. The effect of propagation methods on plant height of Moringa

Seedling transplanting, and stem cuttings resulted in highly significant results compared to direct seeding ($p < 0.001$). These results agree with the findings by Jacob *et al.* (2016) which revealed that seedlings produced by seeds had higher mean height than seedlings produced by stem cuttings. Given that the seeds and stem cuttings were grown in same climatic and edaphic conditions, it follows those variations in their genetic composition are the reason of their disparate heights. It is therefore possible to argue that stem cuttings have a superior genetic make-up than seeds because seedlings produced from stem cuttings had a greater mean height than seedlings produced from seeds. The physiological capacities of the seedlings may also be

responsible for variations in seedling height. The results contradict with the study conducted by Kiragu *et al.* (2015) who revealed that there were no significant differences in seedling height growth propagated through stem cuttings and direct seeding. Stem cuttings and direct seeding demonstrated shorter plant heights, with direct seeding being the least favorable in terms of height attainment. However, in this study, seedling transplanting stands out as the most effective approach, resulting in the tallest plants. This is attributed to factors such as early establishment, enhanced root development and protection from environmental stresses.

5.4. The effect of propagation methods on the number of branches per plant of Moringa

In this study, the number of branches was evaluated as a critical indicator of the overall development and branching pattern of Moringa trees. Seedling transplanting produced highly significant results ($p < 0.001$) compared to other methods. Study conducted by Olorukooba *et al.* (2013) on the influence of planting methods and pinching on growth and vegetative yield of drumstick (*Moringa oleifera* Lam) revealed that the number of branches were not significantly affected by planting methods. A comparative analysis of propagation methods revealed that seedling transplanting yielded the greatest number of branches in *Moringa oleifera* plants, demonstrating its superior effectiveness. Direct seeding also provided a moderate number of branches, making it a practical and cost-effective option. In contrast, stem cuttings demonstrated the lowest number of branches, which may be a limitation for projects that prioritize branching density. The relatively lower branch count in direct seeding could be attributed to the variability in seedling vigor and competition with weeds during the early stages of establishment. The significantly greater number of branches highlights the effectiveness of seedling transplanting in promoting branching.

5.5. The effect of propagation methods on the stem diameter of Moringa

In this comprehensive study on the propagation methods of *Moringa oleifera*, stem diameter was assessed as a key parameter for evaluating the growth and structural development of Moringa trees. Comparing the stem diameters achieved through these propagation methods, seedling transplanting emerged as the most effective approach, resulting in a significantly ($p < 0.001$) larger stem diameter in Moringa plants. Palada *et al.* (2017) reported that differences in stem diameter were significant at 70 days after

transplanting (DAT). The augmentation in stem diameter resulted from continuous growth throughout the experimental duration, with the plants pruned at a height of one meter above the ground. Measurement of this parameter was conducted at a point 10 cm above ground level. Direct seeding and stem cuttings produced relatively similar stem diameters, with direct seeding having a slight edge. However, both direct seeding and stem cuttings may not be optimal for achieving the widest stem diameter. Direct seeding, while producing Moringa plants with relatively thinner stems, may not be the most effective approach for promoting robust stem development. This is attributed to a combination of genetic, environmental, and management factors that influence stem development in Moringa plants grown from direct seeding. The significantly greater stem diameter through seedling transplanting highlights the effectiveness of this method in promoting thicker and more robust stem growth. Controlled nursery conditions offer optimal development opportunities, leading to robust stem development in seedlings that continue to grow when transplanted (Grossnickle and MacDonald, 2018). Stem cuttings may also produce Moringa plants with relatively thinner stems, comparable to direct seeding. The stem diameter in stem cuttings may be influenced by the initial focus on establishing the primary stem rather than promoting wider structural development.

5.6. The effect of propagation methods on the chlorophyll content of Moringa

Chlorophyll content was assessed as a critical parameter for evaluating the photosynthetic activity and overall health of Moringa trees. Seedling transplanting produced significant ($p < 0.001$) results compared to other methods. Monisha *et al.* (2019) demonstrated that the combined influence of foliar spraying and propagation method did not yield notable effects on chlorophyll content. The chlorophyll levels were significantly influenced solely by foliar application and not by propagation methods. The significantly greater chlorophyll concentration highlights the effectiveness of the seedling transplanting method in promoting healthier photosynthetic processes. Controlled nursery conditions offer optimal development opportunities, leading to improved chlorophyll production in seedlings that continue to grow when transplanted (Grossnickle and MacDonald, 2018) In the case of stem cuttings, *Moringa oleifera* plants exhibited the lowest average chlorophyll content. This result suggests that stem cuttings may produce Moringa plants with relatively lower chlorophyll levels compared to the other methods. Lower levels of chlorophyll can result in reduced photosynthetic

efficiency, leading to slower growth rates and diminished overall plant health. The chlorophyll content in stem cuttings may be influenced by factors such as the focus on establishing the primary stem and potentially retaining genetic traits related to photosynthetic efficiency. Rufai *et al.* (2016) found that the SPAD chlorophyll content measurement exhibited a gradual but statistically insignificant linear decline (approximately 13%) in chlorophyll content values as the stem diameter of Moringa cuttings increased from 25-35 mm (treatment 1) to 55-65 mm (treatment 4).

5.7. The effect of propagation methods on the fresh and dry shoot weight of Moringa

The results revealed a notable difference in shoot weight among the three propagation methods. There was a significant difference among all the treatments ($p < 0.001$). Seedling transplanting demonstrated the highest fresh and dry shoot weight compared to stem cuttings and direct seeding. The results of this study align with those reported by Santoso and Parwata (2020), who observed a significant difference in the fresh and dry weight of shoots across different stem cutting lengths. However, they found no significant variance in shoot fresh and dry weight among the three stem cutting diameters examined. Similarly, Olorukooba *et al.* (2013) investigated the influence of planting methods and pinching on the growth and vegetative yield of *Moringa oleifera* Lam. Their findings revealed that the highest fresh vegetative yield was achieved through direct sowing at 2 and 4 weeks after sowing, transplanting at 2 weeks after sowing, and pinching at 2 weeks after sowing. Planting methods significantly impacted cumulative fresh vegetative yield, with optimal results from direct sowing/pinching at and 4 weeks and transplanting/pinching at 2 weeks after sowing. Several factors contributed to the superior performance of seedling transplanting. One significant aspect is the early establishment of a well-developed root system. The seedlings, having undergone a period of growth in a controlled environment, possessed a robust and extensive root structure upon transplanting. This early advantage likely facilitated better nutrient uptake and water absorption, contributing to increased shoot weight (Bashan *et al.*, 2012). Furthermore, the transplanting process allowed for better control over soil conditions and nutrient availability. This may have resulted in a more favorable environment for the growth of *Moringa oleifera*, positively influencing its shoot development. In contrast, stem cuttings and direct seeding might have faced challenges in terms of initial root establishment and competition for resources. The

results align with existing literature on *Moringa oleifera* cultivation, emphasizing the importance of a strong and healthy root system for overall plant growth (Price, 2007).

5.8. The effect of propagation methods on the fresh and dry root weight of Moringa

The investigation into the propagation methods of *Moringa oleifera*, including stem cuttings, direct seeding, and seedling transplanting, unveiled significant variations in the fresh and dry root weights among the different techniques. There was a significant difference in root weights among the treatments ($p < 0.001$). Notably, seedling transplanting emerged as the most successful method, displaying the highest root weights compared to stem cuttings and direct seeding. This development may be associated with the recognition that the Moringa tree is abundant in secondary metabolites, which might have contributed to improving the rooting process, thus leading to the negligible impact of Auxin (Al-Owaisi *et al.*, 2014). In this study, the success of seedling transplanting in promoting greater root development can be attributed to several key factors. Firstly, the seedlings used in the transplanting process had already established a well-developed root system during their early growth phase in controlled conditions. This advantageous root system likely facilitated enhanced nutrient and water uptake, contributing to the observed increase in root weight. Additionally, the controlled environment during seedling growth and transplanting allowed for meticulous management of soil conditions, nutrient levels, and water availability. This may have created a more favorable environment for robust root development compared to the other propagation methods. Stem cuttings and direct seeding, on the other hand, may have encountered challenges in initial root establishment and resource competition. The impact of stem cutting length was linked to the accumulation of carbohydrates, with greater reserves promoting better rooting compared to cuttings with fewer reserves (Hartmann *et al.*, 2002). Santoso and Parwata (2020) observed a significant influence of stem cutting length on root length, root number, and seedling production. These findings regarding Moringa vegetative propagation align with several other studies. The outcomes align with existing literature on *Moringa oleifera* and other plant species, emphasizing the significance of a healthy root system for overall plant vitality.

5.9. The effect of propagation methods on the nutritional composition of the Moringa leaves

There were significant differences in Iron (Fe), Manganese (Mn), Zinc (Zn), and Copper (Cu) concentration observed among all the three methods of propagation used to raise *Moringa oleifera* with a p value of 0.001. This study demonstrated significant differences in potassium (K) content among the different propagation methods. Direct seeding exhibited a potassium content ranging from 2.03% to 2.37%, which was significantly higher compared to seedling transplanting and stem cuttings ($p < 0.001$). This indicates that the potassium content of Moringa leaves is particularly sensitive to the method of propagation, with direct seeding resulting in a substantially higher potassium yield. According to Vieira *et al.* (2008), nitrogen (N) and potassium (K) are the primary macronutrients that tend to accumulate the most in *Moringa oleifera* seedlings, with calcium (Ca), sulfur (S), phosphorus (P), and magnesium (Mg) following suit. These nutrients likely contribute to the development of both the aerial parts and the root system in the *Moringa oleifera* seedlings examined in this study.

There was a significant difference in fat, protein, and ADF concentration ($p < 0.001$) among all the treatments. Stem cuttings led to the highest ADF and NDF concentrations, potentially impacting digestibility, while direct seeding resulted in the highest fat content, making it suitable for specific dietary needs. Seedling transplanting enhanced protein levels, potentially making it the preferred method for applications requiring higher protein content. The findings provide essential insights for selecting the most suitable propagation method based on specific nutritional requirements, such as animal feed, human consumption, or other applications with distinct nutritional profiles. Huque *et al.* (2016) conducted a study on the asexual propagation of Moringa (*Moringa oleifera*), focusing on biomass yield, nutritional composition, and in-sacco dry matter degradability. They found no significant difference in the acid detergent fiber (ADF) content of total foliage, stem, and leaf among the three treatments studied. Additionally, the ADF content of all fractions remained unchanged across different cutting diameters. Similarly, Sodamade *et al.* (2013) demonstrated that *Moringa oleifera* leaves are nutritionally rich and serve as a promising source of dietary minerals. The concentration of minerals in the leaves suggests that the plant could be a significant source of essential elements for human consumption.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

After conducting a comprehensive study comparing different propagation methods of Moringa trees, including direct seeding, stem cuttings, and seedling transplanting, the results suggest that propagation methods indeed have a significant effect on both the growth and yield of Moringa trees, as well as the nutritional composition of their leaves. The study found that Moringa trees propagated through seedling transplanting exhibited faster growth rates and higher yields compared to those propagated through direct seeding and stem cuttings. These findings disprove the hypothesis that propagation methods have no effect on Moringa tree growth, yield, and nutritional composition. Instead, they highlight the importance of selecting appropriate propagation methods to optimize the growth, yield, and nutritional quality of Moringa trees.

In conclusion, the research underscores the significance of the propagation method in influencing the overall success of *Moringa oleifera* production. Seedling transplanting stands out as the optimal choice, demonstrating advantages such as enhanced uniformity, consistent yields, and superior nutritional quality compared to direct seeding and stem cuttings. It can be highlighted that seedling transplanting is a reliable and efficient propagation method for *Moringa oleifera*.

Given its efficacy, there is a strong recommendation to promote seedling transplanting as the preferred method for cultivating *Moringa oleifera*. Farmers and practitioners should be encouraged to adopt this method for optimal results in terms of growth, yield, and nutritional content. Initiating training programs and outreach efforts to educate farmers on the benefits and techniques of seedling transplanting is crucial. This will facilitate widespread adoption and ensure that the agricultural community reaps the maximum benefits of this effective propagation method. While seedling transplanting has shown significant advantages, further research is recommended to explore nuances and potential improvements. Long-term studies can provide insights into the sustained impact of this method and identify strategies for continuous optimization. Moreover, recommendations should include guidelines for adapting seedling transplanting practices to specific local conditions, ensuring that the method is effectively tailored to diverse environmental and agricultural settings.

In summary, this dissertation not only contributes to the understanding of propagation methods for *Moringa oleifera* but also strongly advocates for the widespread adoption of seedling transplanting due to its superior effectiveness in promoting growth, increasing yield, and enhancing nutritional composition.

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APPENDICES

Appendix 1: Analysis of variance for the daily emergence rate of *Moringa oleifera* influenced by different methods of propagation.

Source	DF	SS	MS	VR	P
Reps' stratum	5	692.16	138.43	2.07	
Reps.*Units* stratum					
WAP	6	165082.03	27513.67	411.17	<.001
Treatments	2	45586.96	22793.48	340.63	<.001
WAP. Treatments	12	42269.29	3522.44	52.64	<.001
Residual	100	6691.58	66.92		
Total	125	260322.01			

Appendix 2: Analysis of variance for the plant height of seedlings influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps' stratum	5	2274.12	454.82	12.76	
Reps.*Units* stratum					
WAP	5	1474.90	294.98	8.27	<.001
Treatments	2	6524.01	3262.01	91.51	<.001
WAP.Treatments	10	187.43	18.74	0.53	0.867
Residual	85	3030.05	35.65		
Total	107	13490.52			

Appendix 3: Analysis of variance for the number of branches per plant influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps' stratum	5	80.463	16.093	10.15	
Reps.*Units* stratum					
WAP	5	238.713	47.743	30.11	<.001
Treatments	2	1297.17161	648.586	409.01	<.001
WAP.Treatments	10	185.190	18.519	11.63	<.001
Residual	85	134.787	1.586		
Total	107	1936.324			

Appendix 4: Analysis of variance for the stem diameter influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps' stratum	5	38.9138	7.7828	9.84	
Reps.*Units* stratum					
WAP	5	122.9988	24.5998	31.10	<.001
Treatments	2	198.9111	99.4556	125.72	<.001
WAP.Treatments	10	35.6189	3.5619	4.50	<.001
Residual	85	67.2400	0.7911		
Total	107	463.6825			

Appendix 5: Analysis of variance for the chlorophyll content influenced by different propagation methods.

Source	DF	SS	MS	VR	P
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Reps' stratum	5	654.04			
Reps.*Units* stratum					
WAP	5	5050.02	1010.00	20.81	<.001
Treatments	2	2179.51	1089.75	22.45	<.001
WAP.Treatments	10	2713.03	271.30	5.59	<.001
Residual	85	4126.29	48.54		
Total	107	14722.87			

Appendix 6: Analysis of variance for the fresh shoot weight (FSW) of *Moringa oleifera* influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps' stratum	5	637.56	127.51	5.26	
Reps.*Units* stratum					
Treatments	2	1186.37	593.18	24.45	<.001
Residual	10	242.59	24.26		
Total	17	2066.52			

Appendix 7: Analysis of variance for the dry shoot weight (DSW) of *Moringa oleifera* influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps' stratum	5	61.234	12.247	3.38	
Reps.*Units* stratum					
Treatments	2	100.217	50.109	13.38	0.001
Residual	10	36.220	3.622		
Total	17	197.672			

Appendix 8: Analysis of variance for the fresh root weight of *Moringa oleifera* influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps' stratum	5	1187.7	237.5	1.30	
Reps.*Units* stratum					
Treatments	2	7102.6	3551.3	19.38	<.001
Residual	10	1832.1	183.2		
Total	17	10122.4			

Appendix 9: Analysis of variance for the dry root weight of *Moringa oleifera* influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps' stratum	5	60.66	12.13	1.13	
Reps.*Units* stratum					
Treatments	2	484.38	242.19	22.63	<.001
Residual	10	107.01	10.70		
Total	17	652.04			

Appendix 10: Analysis of variance for Iron (Fe) influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps' stratum	5	1850.7	370.1	2.61	
Reps.*Units* stratum					
Treatments	2	970177.0	485088.5	3424.96	<.001
Residual	10	1416.3	141.6		
Total	17	973444.0			

Appendix 11: Analysis of variance for Manganese (Mn) influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps' stratum	5	31.17	6.23	0.29	
Reps.*Units* stratum					
Treatments	2	1225.00	612.50	28.31	<.001
Residual	10	216.33	21.63		
Total	17	1472.50			

Appendix 12: Analysis of variance for Copper (Cu) influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps' stratum	5	3.1667	0.6333	4.75	
Reps.*Units* stratum					
Treatments	2	36.0000	18.0000	135.00	<.001
Residual	10	1.3333	0.1333		
Total	17	40.5000			

Appendix 13: Analysis of variance for Zinc (Zn) influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps' stratum	5	3.333	0.667	0.18	
Reps.*Units* stratum					
Treatments	2	847.000	423.500	112.43	<.001
Residual	10	37.667	3.767		
Total	17	888.000			

Appendix 14: Analysis of variance for Calcium (Ca) influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps' stratum	5	0.03873	0.00775	0.31	
Reps.*Units* stratum					
Treatments	2	0.35560	0.17780	7.17	0.012
Residual	10	0.24807	0.02481		
Total	17	0.64240			

Appendix 15: Analysis of variance for Potassium (K) influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps' stratum	5	0.0025833	0.0005167	1.37	
Reps.*Units* stratum					
Treatments	2	0.4237000	0.2118500	562.42	<.001
Residual	10	0.0037667	0.0003767		
Total	17	0.4300500			

Appendix 16: Analysis of variance for Magnesium (Mg) influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps' stratum	5	0.02813	0.00563	0.34	
Reps.*Units* stratum					
Treatments	2	0.05430	0.02715	1.63	0.244
Residual	10	0.16657	0.01666		
Total	17	0.24900			

Appendix 17: Analysis of variance for Sodium (Na) influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps' stratum	5	0.0017833	0.0003567	0.50	
Reps.*Units* stratum					
Treatments	2	0.0003000	0.0001500	0.21	0.815
Residual	10	0.0071667	0.0007167		
Total	17	0.0092500			

Appendix 18: Analysis of variance for Phosphorus (P) influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps stratum	5	0.011933	0.002387	1.07	
Reps.*Units* stratum					
Treatments	2	0.006400	0.003200	1.44	0.283
Residual	10	0.022267	0.002227		
Total	17	0.040600			

Appendix 19: Analysis of variance for K/Ca+Mg influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps stratum	5	0.084467	0.016893	1.85	
Reps.*Units* stratum					
Treatments	2	0.024100	0.012050	1.32	0.310
Residual	10	0.091233	0.009123		
Total	17	0.199800			

Appendix 20: Analysis of variance for ADF (Acid Detergent Fibre) influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps stratum	5	20.522	4.104	4.03	
Reps.*Units* stratum					
Treatments	2	49.515	24.757	24.33	<.001
Residual	10	10.175	1.017		
Total	17	80.211			

Appendix 21: Analysis of variance for NDF (Neutral Detergent Fibre) influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps stratum	5	12.228	2.446	0.39	
Reps.*Units* stratum					
Treatments	2	18.722	9.361	1.50	0.270
Residual	10	62.601	6.260		
Total	17	93.551			

Appendix 22: Analysis of variance for Fat influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps stratum	5	0.6578	0.1316	1.14	
Reps.*Units* stratum					
Treatments	2	14.3971	7.1985	62.61	<.001
Residual	10	1.1498	0.1150		
Total	17	16.2047			

Appendix 23: Analysis of variance for Protein influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps stratum	5	8.3322	1.6664	2.85	
Reps.*Units* stratum					
Treatments	2	78.5137	39.2569	67.14	<.001
Residual	10	5.8472	0.5847		
Total	17	92.6930			

Appendix 24: Analysis of variance for Ash influenced by different propagation methods.

Source	DF	SS	MS	VR	P
Reps stratum	5	1.1942	0.2388	0.68	
Reps.*Units* stratum					
Treatments	2	20.0667	10.0334	28.77	<.001
Residual	10	3.4870	0.3487		
Total	17	24.7478			