BINDURA UNIVERSITY OF SCIENCE EDUCATION

FACULTY OF AGRICULTURE AND ENVIRONMENT SCIENCE

EVALUATING THE GROWTH RATE, LEAF AREA INDEX AND FINAL YIELD OF WILD AMARANTHUS SPECIES

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DECLARATION

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The undersigned hereby certify that they have examined and recommend this work for consideration by the department of crop science, this project entitled:

Evaluating the Growth Rate, Leaf Area Index, and final yield of wild Amaranthus Species by Tellme Marichi. A thesis submitted to the Department of Crop Science, Faculty of Agriculture and Environment Science, Bindura University of Science Education in partial fulfilment of requirements for the degree Bachelor of Science Honours in Crop Science.

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ABSTRACT

This study evaluated the growth rate, Leaf Area Index (LAI) and final yield of three wild Amaranthus species namely *Amaranthus viridis, Amaranthus spinosus* and *Amaranthus hybridus* under the same growing conditions at the District Agricultural Centre of Excellence (DACE) in Chegutu District, Zimbabwe. The study was motivated by the limited agronomic information available on commonly occurring wild *Amaranthus* species despite their widespread consumption and nutritional importance. The objectives of the study were to compare the growth rate, determine the LAI and assess the final yield of the selected species. An experimental research design based on a Randomised Complete Block Design (RCBD) was used with three treatments and three replications. Data was collected through direct field measurements of plant height, leaf dimensions and fresh biomass yield. Analysis of Variance (ANOVA) and Tukey HSD tests were used for statistical analysis at $p < 0.05$. The results showed significant differences among the species for growth rate, LAI and final yield. *Amaranthus hybridus* recorded the highest mean growth rate (1.23 cm/day), highest LAI (3.42 at 28 DAP) and highest mean fresh biomass yield (1.01 kg/plot). *Amaranthus viridis* showed rapid early growth and moderate yield performance, while *Amaranthus spinosus* consistently recorded the lowest values across all measured parameters. The findings showed that sustained canopy development and higher LAI contributed more to final biomass yield than early growth alone. The study concluded that *Amaranthus hybridus* performed better under the tested conditions and is more suitable for leafy vegetable production where high biomass yield is required. The study recommends promoting species-specific cultivation of high-performing wild *Amaranthus* species and conducting further studies under different environmental and management conditions to improve production efficiency.

Key words: *Amaranthus* species, growth rate, leaf area index, biomass yield, wild leafy vegetables

DEDICATION

This research project is dedicated to my late parents, Mr. LN Marichi and Mrs. J Marichi. This is for you, Mum and Dad, I have fulfilled your wishes. May your soul rest in peace.

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CHAPTER 1 INTRODUCTION

1.1 Introduction

This study focuses on how selected wild *Amaranthus* species grow and produce yield. Wild Amaranthus plants are commonly found in farming areas and are often eaten as green vegetables but their field performance has not been clearly measured using standard agronomic indicators. There is a need for clear data that shows how these species grow, form leaf canopy, and produce usable biomass so that their value can be evaluated using evidence rather than assumption. To achieve this, the study measures three key crop indicators that is growth rate, leaf area index, and final yield and compares them across selected wild Amaranthus species grown under the same conditions. In doing so, the research adds reliable production data for crops that are widely used but not well studied, and helps improve how their agricultural value is understood. To achieve these objectives, the study is organised into six chapters. Chapter one introduces the study, Chapter two reviews related literature, Chapter three explains the research methods, Chapter four presents the results, Chapter five discusses the findings and Chapter six gives the conclusions and recommendations.

1.2 Background of the study

Wild Amaranthus species (*Amaranthus* spp.) are naturally growing leafy plants that are commonly found in crop fields and open land (Achigan-Dako et al., 2014). According to Ebert (2014), many communities harvest and eat them as traditional vegetables because they grow quickly and can produce edible leaves within a short time. Researchers describe Amaranthus as a hardy and adaptable plant group that performs well under a wide range of environmental conditions such as heat and moderate soil stress (Jasrotia and Salgotra, 2021). Due to these qualities, Amaranthus species are recognised as an important underutilised crop with potential to support vegetable supply and household nutrition, especially in low-input farming systems (Talucder *et al.*, 2024). However, most formal agronomic studies have focused on cultivated amaranth varieties, whilst wild species have not been studied in the same structured and measured way.

Plant performance in agronomy is usually evaluated using clear and measurable indicators. Growth rate refers to how fast a plant increases in size or biomass over a given period of time

(Mabala, 2018). This measure helps researchers understand how quickly a crop establishes and uses available resources. Leaf Area Index is defined as the total leaf surface area compared to the ground area covered by the crop canopy and it is used to show how well the plant canopy can capture sunlight for photosynthesis (Jamalluddin, 2020). Final yield refers to the total usable harvested biomass at the end of the growing period and is widely used as the main indicator of crop productivity (Das, 2016). When these three measures are taken together, they give a balanced picture of how a crop grows, develops its canopy and converts growth into harvestable output.

Research by Viljoen (2018), shows that wild Amaranthus species show visible differences in plant height, leaf size, branching pattern and maturity period. These differences suggest that not all wild Amaranthus plants perform the same in terms of growth and yield. Even so, most research work treats them as one general category and does not measure the performance of each species individually. Many published studies on Amaranthus have examined fertiliser application and water management in cultivated vegetable amaranth, rather than comparing the growth behaviour of wild species under the same conditions (Jamalluddin, 2020; Mopai, 2023; Viljoen, 2018). This means that there is limited controlled data showing how different wild Amaranthus species compare in their growth rate, leaf area development and final yield.

Another challenge is that leafy vegetables are often evaluated mainly by final yield, without measuring how that yield is formed during the growth period. Two species can produce similar harvest weights but reach that outcome through different growth speeds and canopy structures. Without measuring growth rate and leaf area index, it is difficult to explain why one species performs better or worse than another (Piao et al., 2020). For leafy crops such as wild Amaranthus, leaf development is directly linked to usable yield, so canopy measurements are very important.

There is therefore a clear need for a structured agronomic study that measures and compares wild Amaranthus species using standard crop science indicators. At present, nutritional and traditional use information is more common than measured growth and yield data for these species

(Talucder *et al*., 2024). This creates a gap between how widely the plants are used and how well they are scientifically understood from a production point of view.

This study focuses on three wild Amaranthus species which are green amaranth (*Amaranthus viridis),* Spiny amaranth (*Amaranthus spinosus*) and Pigweed (*Amaranthus hybridus).* These species were chosen because they are common in smallholder farming communities in Zimbabwe and often grow naturally in crop fields. They are easy to identify in the field which makes data collection more accurate. They also differ in plant structure and canopy shape. This makes them suitable for comparing growth rate, leaf area index and final yield under the same growing conditions. These three indicators are used to measure the selected species under the same growing conditions so that the results can be compared fairly. This will produce clear data on how each species grows and how much it yields. The aim is to improve understanding of their field performance and help identify which species are more suitable for vegetable production.

1.3 Statement of the Problem

Wild Amaranthus species are widely eaten across sub-Saharan Africa and are valued for their good nutritional content and ability to grow under dry and hot conditions. However, they are still underused and not well studied in terms of their field growth and production performance (Mabhaudhi *et al*., 2017; Ruth *et al*., 2021). Research by Emmanuel and Babalola (2022) shows that wild amaranth can reach yields of up to 32 t ha^{-1} under good management. However, actual yields are often much lower because there have been few well-designed agronomic studies and limited field data. Most existing studies focus on improved or cultivated types. Common wild species such as *Amaranthus viridis*, *A. spinosus* and *A. hybridus* which frequently grow on their own, have rarely been compared using standard growth measurements (Kodzwa *et al*., 2023; Mphande, 2025). Many studies on African indigenous vegetables also focus more on nutritional value than on measured indicators like growth rate, Leaf Area Index and yield development under controlled conditions (Mopai, 2023). This means there is still not enough experimental evidence to explain yield differences among wild Amaranthus species. This demonstrates the need for a controlled comparative growth and yield study.

1.4 Justification of the Study

This study needs to be carried out because wild Amaranthus species are already widely eaten but there is not enough measured field data showing how well different species actually grow and yield. Farmers often use these plants because they appear naturally and mature quickly but they do not have tested information on which species performs better in terms of growth speed, canopy development and harvestable output. Extension services and indigenous vegetable promotion programs also lack clear species-by-species agronomic data. Without this evidence, advice on which wild amaranth species encourage or manage is based mostly on observation and tradition. This study provides measured and comparable data on growth rate, leaf area index and final yield which is needed to support evidence-based decisions in leafy vegetable production.

The study is also important for research because most published work on Amaranthus focuses on nutrition or on improved varieties not on the measured field performance of common wild species. This leaves a gap between what is known about their food value and what is known about their production performance. This study adds clear agronomic evidence to the knowledge base. This information can be used by other researchers in future studies or species improvement work. It also provides a reliable reference point for comparing wild and cultivated amaranth types in future research.

1.5 Study Objectives

1. To measure and compare the growth rate of *Amaranthus viridis*, *Amaranthus spinosus* and *Amaranthus hybridus* under the same growing conditions.
2. To determine and compare the leaf area index of the selected wild Amaranthus species during the growth period.
3. To assess and compare the final yield of the selected wild Amaranthus species at harvest.

1.6 Hypotheses

1. There is no significant difference in growth rate among *Amaranthus viridis*, *Amaranthus spinosus* and *Amaranthus hybridus* grown under the same conditions.

2. There is no significant difference in leaf area index among *Amaranthus viridis*, *Amaranthus spinosus* and *Amaranthus hybridus* grown under the same conditions.
3. There is no significant difference in final yield among *Amaranthus viridis*, *Amaranthus spinosus* and *Amaranthus hybridus* grown under the same conditions.

CHAPTER 2 LITERATURE REIEW

2.1 Introduction

The aim of the chapter is to show what is already known about growth rate, Leaf Area Index (LAI) and final yield and how these factors affect the performance of amaranth crops. The chapter discusses general growth behaviour, differences among species, environmental factors that influence growth and methods used in previous studies to measure growth. It also looks at findings from different studies to show current knowledge and identify areas that still need more research. The chapter then outlines the research gap and shows the need for a comparative study of wild *Amaranthus* species under controlled conditions.

2.2 Growth Characteristics of *Amaranthus* Species

2.2.1 General Growth Behaviour of *Amaranthus* spp.

Rapid vegetative growth is one of the main characteristics of the *Amaranthus* genus. Ebert (2014) explains that amaranth is a fast-growing leafy vegetable that can produce harvestable biomass within a few weeks after emergence which makes it suitable for short production cycles and low-input farming systems. In the same way, Mabhaudhi et al. (2017) note that underutilised crops such as amaranth use resources efficiently and adapt well to marginal environments which allows continued vegetative growth even under moderate stress conditions. Talucder et al. (2024) also support this view where they reported that amaranths consistently show rapid establishment and high biomass production compared to many other indigenous leafy vegetables. This shows that they have strong agronomic potential.

Field studies also confirm this rapid growth characteristic. Mopai (2023), in a controlled experiment that evaluated three amaranth species under an organic trough system, observed rapid increases in plant height and leaf biomass in the first four weeks after planting. The study also showed clear differences among species in growth dynamics. Similarly, Mabala (2018) found that indigenous leafy vegetables such as amaranth, displayed faster early vegetative growth when sufficient nitrogen was applied, indicating that nutrient availability strongly influences growth rate. However, Kodzwa et al. (2023) caution that although amaranths are often described as vigorous crops, many studies rely on simple indicators such as plant height instead of calculating actual growth rates which limits accurate comparison across species.

2.2.2 Species-Specific Growth Traits (*A. viridis*, *A. spinosus*, *A. hybridus*)

Growth characteristics vary across species within the *Amaranthus* genus. Achigan-Dako et al. (2014) reported significant differences in plant structure, leaf shape and branching patterns among African leafy amaranths. They noted that the structure of the canopy directly affects biomass production. *Amaranthus hybridus* is commonly described as vigorous and highly branched which increases cumulative leaf area and supports greater vegetative biomass under favourable conditions (Viljoen, 2018). On the other hand, *A. viridis* is generally characterised by moderate plant height and rapid leaf expansion during early growth. This is a characteristic that may promote faster establishment (Mopai, 2023).

Amaranthus spinosus which is recognised by its spiny stem nodes and upright growth habit, may allocate more biomass to structural tissues compared to softer-stemmed species (Achigan-Dako et al., 2014). This structural investment can influence how biomass is divided between stems and leaves and may affect the overall growth rate. Adedibu et al. (2024) also observed that variation within *A. hybridus* cultivars was linked to differences in vegetative growth and leaf biomass accumulation which suggests that growth responses can vary even within the same species.

Despite these observations, Jamalluddin (2020) points out that many studies focus on drought tolerance or morphological diversity rather than directly comparing growth rates under the same conditions. As highlighted in the previous chapter, wild species such as *A. viridis*, *A. spinosus* and *A. hybridus* are often grouped together in research which leads to limited side-by-side experimental comparisons that clearly quantify differences in growth rate.

2.2.3 Environmental Influence on Growth Rate

Environmental conditions play a major role in determining growth characteristics in *Amaranthus* species. Jasrotia and Salgotra (2021) explain that germplasm of underutilised crops such as amaranth shows adaptive growth responses to heat and moderate soil stress. This allows continued vegetative development even under less favourable conditions. Likewise, Mabala (2018) demonstrated that higher nitrogen application significantly increased biomass accumulation and leaf expansion, especially during early vegetative growth which goes on to show the importance of soil fertility in determining growth performance.

Water availability is another key factor that influences growth. Jamalluddin (2020) found that

drought stress reduced leaf expansion and slowed biomass accumulation in amaranth germplasm, although tolerant genotypes maintained relatively stable growth compared to sensitive ones. However, Platonova et al. (2023) reported that environmental variation explained between 22% and 58% of phenotypic differences in red amaranth grown under temperate conditions. This indicates that climate can strongly influence vegetative expression. These findings suggest that although genetic differences affect growth potential, environmental factors can either enhance or suppress species-level differences.

Shayanowako et al. (2021) also observed that African leafy vegetables often perform differently across agroecological zones due to differences in rainfall and soil fertility. This variation shows the importance of controlled experiments where selected species are grown under the same conditions so that true growth differences can be accurately identified.

2.2.4 Methodological Approaches Used to Measure Growth in Previous Studies

Different methods have been used to measure growth characteristics in *Amaranthus* studies. Mopai (2023) used sequential harvesting and fresh weight measurements to monitor biomass accumulation over time, whereas Mabala (2018) applied periodic sampling and dry weight measurements to assess growth responses under different nitrogen treatments. Although these methods provide useful estimates of biomass production, they do not always calculate standard growth indicators such as relative growth rate (RGR) or crop growth rate (CGR).

Jamalluddin (2020) included measurements such as leaf area and biomass under stress conditions but growth was mainly interpreted through trait performance rather than dynamic growth analysis. Kodzwa et al. (2023) further note that many studies on indigenous vegetables focus on improving yield without measuring growth rate throughout the production cycle. As a result, two species may reach similar final yields even though they differ significantly in growth speed and canopy development.

The limited use of repeated dry matter sampling and formal growth analysis reduces understanding of how biomass accumulates over time in different wild species. Without standardised measurements taken under the same environmental conditions, it is difficult to determine whether differences in yield result from inherent growth advantages or from external factors. Therefore, a controlled comparative study that measures growth rate among *A. viridis*, *A. spinosus* and *A. hybridus* is necessary to provide measurable evidence of growth performance

that is specific to each specie.

2.3 Leaf Area Index in Wild *Amaranthus* Species

2.3.1 Canopy Development in *Amaranthus* Species

Canopy development in *Amaranthus* species is mainly driven by fast leaf expansion and branching which allow the plants to cover the ground quickly. Islam et al. (2024), in a study on vegetable amaranth grown under different spacing arrangements, found that canopy closure occurred within four to five weeks after planting. Their results showed clear differences in leaf area development among accessions. Plants grown at wider spacing produced larger individual leaves but the overall leaf area index (LAI) per unit ground area was lower. This shows that plant density and canopy structure work together to determine the final LAI. Similarly, Hirani et al. (2024) evaluated leafy amaranth varieties under field conditions and reported that species with higher branching intensity developed higher LAI values during the mid-vegetative stage. This increase in LAI contributed to higher fresh leaf yield. The study also showed that canopy features such as leaf angle and branch arrangement strongly influence how efficiently plants capture light. Noor et al. (2024) also found that genotypes with broader leaves and more horizontal leaf arrangement achieved higher LAI values than narrow-leaved types. These findings indicate the importance of morphological traits in shaping canopy performance and overall productivity.

Although most of these studies focus on cultivated amaranth types, they provide useful understanding of canopy development processes that may also apply to wild species. However, direct comparisons of LAI development among *A. viridis*, *A. spinosus* and *A. hybridus* grown under the same conditions are still limited.

2.3.2 Methods of Measuring Leaf Area Index

Leaf area index can be measured using either destructive or non-destructive methods. Tripathi et al. (2024) explain that direct methods involve harvesting leaves and measuring their area using tools such as digital scanners. Total leaf area is then related to the ground area to calculate LAI. Although this method is accurate, it requires a lot of labour and disturbs the crop canopy. In contrast, indirect optical methods such as canopy analysers estimate LAI using light interception principles and allow quick measurements without damaging plants (Weiss et al., 2004).

Recent technological advances have made LAI measurement easier and more precise. Mir et al. (2024) used UAV-based multispectral imaging to estimate LAI in leafy vegetable systems and found strong agreement between remotely sensed data and ground measurements. Similarly, Fernandes et al. (2025) applied smartphone-based imaging methods to estimate canopy cover and LAI with acceptable accuracy for smallholder vegetable systems. These developments show that LAI measurement is becoming more accessible and practical for field studies.

However, many studies on wild leafy vegetables still rely on simple indicators such as plant height or leaf count instead of calculated LAI values. This limits accurate comparison of canopy development across species and growth stages.

2.3.3 Reported LAI Values and Research Gaps in Wild *Amaranthus*

Studies that clearly report LAI values in amaranth are still limited compared to crops such as cereals. Naidu et al. (2024) noted that C4 weeds such as amaranth species show strong biomass and LAI responsiveness to environmental conditions. In leafy vegetable systems, peak LAI values between approximately 3.0 and 5.0 during mid-vegetative stages have been reported under optimal nutrient supply (Islam et al., 2024). Similarly, Sarker and Islam (2023) observed significant genotype-based differences in growth performance in vegetable amaranth which were associated with canopy expansion and leaf development traits.

Despite these findings, most studies do not separate data for wild species or monitor LAI changes throughout the entire growth period. Many researchers measure LAI at only one stage of growth which makes it difficult to understand how canopy development changes over time. Side-by-side comparisons of wild species such as *Amaranthus viridis*, *A. spinosus* and *A. hybridus* under controlled and standardised conditions are still rare in the available research.

This lack of comparison creates an important knowledge gap in understanding how canopy development contributes to yield differences among wild amaranths. Since leaf biomass is the main harvested product, tracking LAI throughout the growth cycle is essential for explaining productivity differences. Therefore, a controlled experimental study that measures LAI dynamics among selected wild *Amaranthus* species is necessary to provide clear evidence that links canopy development to growth performance and final yield.

2.4 Yield Formation and Final Yield in *Amaranthus* Species

2.4.1 Yield Components in *Amaranthus*

Yield in vegetable amaranth is influenced by several measurable factors such plant density, number of harvestable leaves, average leaf size, stem tenderness and branching intensity. Emeghara et al. (2025) examined different spacing arrangements and found that moderate plant density produced the best fresh leaf yield. This was because it balanced individual plant growth with total field productivity. Higher plant densities increased total yield per hectare but reduced leaf size due to competition between plants. This shows that canopy structure and plant population together determine how yield develops.

Sari et al. (2024) reported that nitrogen fertilisation significantly increased leaf number, leaf area and fresh biomass yield in vegetable amaranth. Their findings confirm that nutrient-driven vegetative growth directly improves harvestable output. Similarly, Adedibu et al. (2024) found that genotypes with more lateral branches and horizontally arranged leaves produced higher fresh leaf yields than upright, less-branched types. These results show that plant architecture, especially branching pattern and leaf arrangement, plays an important role in determining yield. Another study by Walters et al. (2019) in the United States showed that harvest frequency influences cumulative yield in leafy amaranth. Another study by Carrasco et al. (2025) showed that harvest management and substrate conditions influence cumulative biomass yield in amaranth. This suggests that vegetative resilience and the ability to regenerate after cutting are important factors that contribute to final yield.

2.4.2 Reported Yields of Wild and Vegetable *Amaranthus* Species

Reported yields of vegetable amaranth vary widely across regions due to differences in genotype, environment and management practices. Sefasi et al. (2025) recorded fresh leaf yields ranging from 18 to 28 t ha^{-1} among different amaranth genotypes grown under open-field conditions. These differences were mainly linked to canopy density and vegetative vigor. Sarker et al. (2024) found that vegetable amaranth produced higher yields during cooler months. This shows that seasonal temperature variation strongly affects biomass accumulation.

Under temperate conditions, Mătieș et al. (2024) reported that vegetative yield depended heavily

on sowing time and climate. Later planting dates reduced fresh biomass because the vegetative growth period became shorter. Similar observations were made in South America, where Mukuwapasi et al. (2024) found large differences in fresh leaf yield among *Amaranthus* accessions grown under the same management conditions, suggesting strong genetic influences on yield performance.

Although these studies provide valuable information on vegetable amaranth productivity, few studies compare naturally occurring wild species such as *Amaranthus viridis, A. spinosus* and *A. hybridus* under the same field conditions. Most existing research focuses on cultivated or improved varieties.

2.4.3 Factors Affecting Final Yield

Final yield in *Amaranthus* species is influenced by genetic characteristics and environmental conditions. Nutrient availability is one of the most important factors that control leaf biomass production. Emeghara et al. (2025) showed that balanced nitrogen application improved vegetative growth and extended the harvest period in leafy vegetables such as amaranth. Similarly, Sari et al. (2024) found that integrated nutrient management increased leaf chlorophyll content, improved canopy density and raised total fresh yield.

Water availability also has a strong influence on yield. Minguet (2024) reported that moderate water stress reduced vegetative biomass accumulation in leafy crops, including amaranth, although tolerant genotypes maintained relatively stable yields. Temperature is another key factor, since excessive heat can speed up flowering and shorten the vegetative phase which reduces leaf biomass production (Kaur et al., 2024).

2.5 Research Gap

The literature shows that *Amaranthus* species are fast-growing plants that adapt well to different environmental conditions and can produce good yields. Their growth rate is influenced by genetic factors such as branching and flowering time. Leaf Area Index (LAI) is widely used as an important indicator of canopy development because it shows how well the plant captures sunlight which directly affects biomass production. Final yield in vegetable amaranth depends mainly on how long the plant remains in the vegetative stage and how efficiently it uses available resources. Many studies show that amaranth can produce high fresh biomass under good

management, but yield is strongly linked to growth patterns and canopy development throughout the growing period.

However, there are still important gaps in this existing research. Most studies focus on cultivated varieties, fertilizer management, spacing or stress tolerance rather than direct comparisons of wild species. There is limited research that compares the growth rate, leaf area index and final yield of *Amaranthus viridis*, *Amaranthus spinosus* and *Amaranthus hybridus* under the same conditions. Growth rate, LAI and yield are often studied separately instead of being analysed together. This lack of combined and comparative information makes it difficult to clearly understand which wild species perform better. Therefore, a controlled field study that measures growth rate, canopy development and final yield together is necessary to fill this gap and provide clear evidence on the performance of these wild *Amaranthus* species.

2.6 Chapter Summary

Available literature was reviewed on the growth, canopy development and yield performance of *Amaranthus* species. The review showed that amaranths are fast-growing and adaptable crops whose growth and yield are influenced by both genetic characteristics and environmental factors. It also explained that Leaf Area Index (LAI) is important because it shows how the canopy develops and how well the plant captures sunlight for biomass production. Although many studies have been done on cultivated amaranth, there is still limited research that directly compares wild species such as *Amaranthus viridis*, *A. spinosus* and *A. hybridus* under the same conditions. As such. A research gap was identified which showed the need for a study that measures growth rate, canopy development and final yield together to better understand the performance of these wild species. The next chapter presents the research methodology used to address the objectives of this study.

CHAPTER 3 MATERIALS AND METHODS

3.1 Description of the Study Area

The study was conducted at the District Agricultural Centre of Excellence (DACE) in Ward 20, Chegutu District, Zimbabwe (approximately 17.93° S, 30.15° E). The area falls under Agro-ecological Region IIb which is suitable for crop production due to relatively reliable rainfall ranging between 750–1000 mm per year. The climate is characterised by moderate temperatures with warm summers and mild winters. The terrain is generally flat to gently undulating and soils are predominantly sandy loam to clay loam which are suitable for vegetable crop production, including Amaranthus.

The study area is primarily used for crop production and agricultural research activities under controlled management conditions. Standard agronomic practices such as land preparation, planting, weeding and watering were applied uniformly across all plots. Water was supplied from available sources such as boreholes to supplement rainfall where necessary. These controlled conditions ensured uniform crop establishment and minimised environmental variation.

3.2 Study Design

The study adopted an experimental research design conducted under controlled field conditions. This design was appropriate because the study aimed to measure and compare the growth rate, leaf area index (LAI) and final yield of selected wild Amaranthus species under the same environmental conditions. Controlling factors such as soil conditions, spacing and management practices ensured that any observed differences were due to species characteristics rather than external influences.

The experiment was laid out using a Randomised Complete Block Design (RCBD). This design was selected to minimise the effects of field variability by grouping similar experimental units into blocks. Each block contained all the treatments and random allocation of treatments within each block was done to reduce bias.

The study focused on three wild Amaranthus species, namely *Amaranthus viridis*, *Amaranthus spinosus* and *Amaranthus hybridus*. These species were selected because they are commonly found and widely consumed in Zimbabwe which makes them suitable for a comparative

evaluation of growth performance, leaf area development and yield potential.

The experiment consisted of three treatments replicated three times, giving a total of nine experimental plots, as shown in Table 3.1.

Table 3.1: Experimental Design Summary

Treatment Code	Species Name	Number of Replications	Total Plots
T1	Amaranthus viridis	3	3
T2	Amaranthus spinosus	3	3
T3	Amaranthus hybridus	3	3
Total			**9**

Each plot was of uniform size and was subjected to the same agronomic practices throughout the study period. This ensured consistency and reliability in comparing the performance of the three Amaranthus species.

3.3 Data Collection Tools and Procedures

Data were collected using direct field measurements, a ruler/measuring tape, a weighing scale and field data recording sheets. The variables of interest were growth rate, leaf area index (LAI) and final yield of Amaranthus viridis, Amaranthus spinosus and Amaranthus hybridus. The experiment followed a Randomised Complete Block Design (RCBD) with three treatments and three replications.

For Objective 1 (growth rate), plant height was measured using a measuring tape from the base of the plant at soil level to the tip of the plant. Measurements were taken at 7-day intervals from establishment up to maturity using the same tagged plants. Growth rate was calculated using the formula:

$$Growth\ Rate\ = \frac{H_2 - H_1}{T_2 - T_1}$$

Where:

H_2= plant height at later time

H_1= plant height at earlier time

$T_2 - T_1$= time interval in days

For Objective 2 (leaf area index), leaf measurements were taken at 14, 21 and 28 days after planting. Fully expanded leaves were selected and leaf length and maximum width were measured using a ruler. Leaf area was estimated using:

$$Leaf\ Area\ =\ Length\ \times Width\ \times k$$

Where:

k= correction factor (0.75)

Leaf Area Index was then calculated as:

$$LAI\ =\ \frac{Total\ Leaf\ Area}{Ground\ Area}$$

For Objective 3 (final yield), plants were harvested at maturity (5 weeks after planting) from the net plot area. The harvested plants were weighed using a weighing scale. Yield was expressed per unit area using:

$$Yield = \frac{Total\ Weight}{Plot\ Area}$$

Only data from uniform and healthy plants were considered. Plants affected by poor establishment or damage were excluded.

Data collection followed a clear sequence. Plots were established and labelled, sample plants were tagged after establishment, growth measurements were taken weekly, leaf measurements were taken at specified stages and yield data were collected at harvest. All data were recorded immediately in the field.

The data were analysed using analysis of variance (ANOVA) for RCBD using the model:

$$Y_{ij} = \mu + B_i + T_j + e_{ij}$$

Where:

Y_{ij}= observed value

μ= overall mean

B_i= block effect

T_j= treatment effect

e_{ij}= random error

3.3.1 Quality Control Procedures

The use of a Randomised Complete Block Design (RCBD) helped control field variability whilst replication of treatments improved the reliability of results. Measurements were taken from the same tagged plants throughout the study to maintain consistency. All instruments such as the weighing scale were checked and calibrated before use to minimise measurement errors. Data were collected at fixed intervals and using standardised procedures across all plots to ensure uniformity. Only healthy and uniformly established plants were considered for measurement to avoid biased results. In addition, all data were recorded immediately in the field to reduce recording errors and improve accuracy.

3.4 Data Analysis

Data collected on growth rate, leaf area index (LAI) and final yield were analysed using Analysis of Variance (ANOVA) which is appropriate for a Randomised Complete Block Design (RCBD). The analysis was conducted using GenStat statistical software. ANOVA was selected because it is suitable for comparing means of more than two groups under an experimental design with replications.

For Objective 1 (growth rate), mean plant height and calculated growth rates for the three species were subjected to ANOVA to determine whether there were statistically significant differences among Amaranthus viridis, Amaranthus spinosus and Amaranthus hybridus.

For Objective 2 (leaf area index), LAI values measured at different growth stages were analysed using ANOVA to compare the leaf development among the three species.

For Objective 3 (final yield), fresh biomass yield per plot was analysed using ANOVA to test for significant differences in yield among the three species.

In all cases, the level of significance was set at $p < 0.05$. Where significant differences were detected at $p < 0.05$, mean separation was performed using Fisher's Protected Least Significant Difference (LSD) test.

The statistical model used for analysis was:

$$Y_{ij} = \mu + B_i + T_j + e_{ij}$$

Where:

Y_{ij}= observed value for the dependent variable

μ= overall mean

B_i= effect of the ith block

T_j= effect of the jth treatment (species)

e_{ij}= random error term

Before analysis, data were checked for normality and homogeneity of variance which are key assumptions of ANOVA. Results were presented using means and standard deviations and tables and graphs were used to illustrate differences among treatments.

CHAPTER 4 RESULTS

4.1 Growth rate at 7 DAP

Table 4.1 Effect of Amaranthus species on growth rate at day 7 DAP (cm/day

Species	**7 DAP (cm/day)**
A.spinosus	0.980[a]
A.viridis	1.140[b]
A.hybridus	1.237[c]
P-value	0.001
LSD (5%)	0.05902
CV (%)	2.3

Means followed by different letters are significantly different at P ≤ 0.05.

Species had an effect on the growth of wild Amaranthus ($p<0.05$). *A. hybridus* had the highest growth rate at 1,237cm/day and *A. viridis* following with medium growth rate at 1.14 cm/day, while *A. spinosus* had the lowest growth rate at 0.98cm/day. The growth rates of the three species were all significantly different from each other

Table 4.2 Effect of Amaranthus species on LAI at 14 DAP, 21DAP and 28DAP

Species	**Mean LAI 14DAP**	**Mean LAI 21DAP**	**28DAP**
A.spinosus	0.940[a]	22.80[a]	2.310[a]
A. viridis	1.120[b]	26.10[b]	2.940[b]
A. hybridus	1.210[c]	27.40[c]	3.420[c]
Grand Mean	1.090	25.43	2.890
LSD (5%)	0.04719	0.693	0.0907
CV (%)	1.9	1.2	1.4
P-Value	<0.001	<0.001	<0.001

Means followed by the same letter are significantly different from each other

Species had an effect on the LAI of Amaranthus ($p<0.05$). for all the three measuring points, *A. hybridus* maintained the highest LAI (1.210, 27.40, 3.420) while *A. spinosus* maintained the lowest LAI (0.940,22.80,2.310) and *A.viridis* at intermediate LAI (1.120,26.10,2.940.The three species were also consistently different from each other.

4.3 Effect of Amaranthus species on yield (g/plant) 7DAP and 21DAP

Species	**Mean 7DAP**	**Mean 21 DAP**
A.spinosus	0.510^{a}	27.1^{a}
A.viridis	0.813^{b}	30.5^{a}
A.hybridus	1.007^{c}	32.7^{a}
Grand mean	0.777	30.1
LSD (5%)	0.0868	10.40
CV (%)	4.9	15.2
P-value	<0.001	0.407

Means followed by different letters are significantly different at $P \leq 0.05$.

Species had a highly significant effect of ($P < 0.001$, $F = 128.20$) indicates clear yield differences among species at all two measured 7DAP and 21 DAP periods. *A. hybridus* produces the highest yield of (1.007, 30.1) at 7DAP followed by *A. viridis* with (0.813, 30.5) and lowest yield was *A. spinosus* (0.510, 27.1).

CHAPTER 5 DISCUSSION

5.0 Discussion

5.1 Growth Rate of Amaranthus Species

The results showed a highly statistically significant difference in growth rate among the species ($p < 0.001$). Amaranthus hybridus recorded the highest growth rate, followed by A. viridis, whilst A. spinosus recorded the lowest growth rate. However, A. viridis grew faster during the early growth stages before being overtaken by A. hybridus at later stages of development.

The early advantage of *A. viridis* is likely due to rapid leaf expansion and efficient early use of resources. Mopai (2023) and Ebert (2014) both report that amaranth species establish quickly through fast early growth. This explains why *A. viridis* performed better at the beginning. However, this advantage reduced as the plants grew and competition increased.

The later dominance of *A. hybridus* can be linked to its ability to sustain growth over time. Viljoen (2018) describes *A. hybridus* as a highly branched species. As the plants moved into the mid-growth stage (around weeks 3–5), branching likely increased leaf production which allowed *A. hybridus* to continue growing whilst *A. viridis* slowed down. This explains the crossover observed in the results.

Amaranthus spinosus consistently recorded the lowest growth rate. This can be explained by its growth structure. According to Achigan-Dako et al. (2014), this species allocates more biomass to stems which limits rapid vegetative growth. However, some variation was observed across replications, where *A. spinosus* showed inconsistent growth between measurement periods. This is a normal exception and can be attributed to natural variability.

These results show that growth rate depends on the growth stage. *A. viridis* is more suitable for short growing periods because of its fast early growth. *A. hybridus* is better for longer production cycles where sustained growth is needed.

5.2 Leaf Area Index (LAI) of Amaranthus Species

The results showed that Leaf Area Index (LAI) increased over time for all three species, with a highly statistically significant difference observed among them ($p < 0.001$). *Amaranthus*

hybridus consistently recorded the highest LAI, followed by *A. viridis*, whilst *A. spinosus* had the lowest values throughout the growth period. This indicates that canopy development was different across species under the same conditions.

The steady increase in LAI across all species shows normal canopy development as plants grow and produce more leaves. Islam et al. (2024) reported that canopy expansion in amaranth increases rapidly during the vegetative stage which aligns with the upward trend observed in this study. However, the rate of increase slowed at later stages which suggests that canopy development begins to stabilise as plants approach maturity.

The higher LAI observed in *A. hybridus* can be explained by its growth structure. Hirani et al. (2024) found that species with higher branching intensity tend to develop greater leaf area. This supports the results, as *A. hybridus* likely produced more branches and leaves over time, leading to a denser canopy. Noor et al. (2024) also states that broader and more horizontally arranged leaves improve canopy coverage which may have contributed to the higher LAI in this species.

Amaranthus viridis showed moderate LAI values despite its strong early growth. This suggests that early height increase does not always result in maximum canopy development. On the other hand, *A. spinosus* recorded the lowest LAI which can be attributed to its more upright growth habit and smaller leaf spread. This limits canopy expansion and reduces overall leaf area.

An exception to the general pattern was the slight difference in LAI values between replications, particularly in *A. hybridus*, where some plots showed slightly higher canopy development than others. This difference may be due to minor differences in plant spacing or micro-environmental conditions.

These findings show that LAI is strongly influenced by plant structure rather than growth rate alone. *A. hybridus* which had higher LAI, developed a more efficient canopy, whereas *A. spinosus* had limited canopy expansion. This supports the view by Kodzwa et al. (2023) that relying only on simple growth indicators such as height can be misleading when assessing plant performance.

Species with higher LAI, such as *A. hybridus*, are more suitable for production systems where maximum leaf biomass is required. This study demonstrates how canopy development differs

among wild Amaranthus species over time which has not been well quantified in previous research.

5.3 Final Yield of Amaranthus Species

Amaranthus hybridus produced the highest yield, followed by A. viridis, whilst A. spinosus recorded the lowest yield. The results further showed a highly statistically significant difference in fresh biomass yield among the three species ($p < 0.001$), indicating clear variation in yield performance under the same growing conditions.

The higher yield of *A. hybridus* can be explained by its ability to maintain growth and develop a larger canopy over time. As shown in the results, this species had both sustained growth and the highest LAI which likely improved light interception and biomass accumulation. Sari et al. (2024) report that increased leaf area and vegetative growth directly contribute to higher fresh biomass yield in amaranth. This supports the findings of this study.

Amaranthus viridis produced moderate yield despite its strong early growth. This suggests that early growth alone does not determine final yield. Although *A. viridis* established quickly, it did not maintain the same level of canopy development as *A. hybridus* which limited its overall biomass production. This highlights the importance of sustained growth and canopy expansion in determining yield.

The low yield of *A. spinosus* is consistent with its lower growth rate and LAI. As noted by Achigan-Dako et al. (2014), this species allocates more biomass to structural components such as stems which reduces the proportion of harvestable leaf material. This explains why it produced lower yield even when plant height differences were not always large.

These findings show that final yield is not determined by growth rate alone but by the combined effect of growth pattern and canopy development. Species with sustained growth and higher LAI, such as *A. hybridus*, are more likely to produce higher biomass. Emeghara et al. (2025) reached similar conclusions as they also emphasised that yield in amaranth is influenced by plant structure and vegetative development.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions of the Study

The study concludes that productive superiority in wild Amaranthus species is mainly determined by the ability to sustain vegetative growth and maintain canopy expansion over time rather than by rapid early establishment alone. Species that continuously expand leaf area during the growth cycle are able to convert growth more effectively into harvestable biomass. This means that sustained canopy development is a stronger determinant of final yield than initial growth speed in leafy vegetable crops.

The study further concludes that canopy structure plays a direct role in determining production efficiency in wild Amaranthus species. Species with broader and denser canopy development achieve greater biomass accumulation because they maintain higher photosynthetic surface area throughout the vegetative stage. On the other hand, species with restricted canopy expansion produce lower usable biomass even where plant growth was visibly present. This establishes Leaf Area Index as a critical agronomic indicator for evaluating leafy vegetable productivity.

Another important conclusion is that wild Amaranthus species possess distinct production capacities and therefore cannot be treated as a single homogeneous crop group in agronomic evaluation or vegetable promotion programmes. The observed differences in growth behaviour, canopy development and biomass accumulation show that species identity significantly influences production outcomes under the same growing conditions. This means that the productive value of wild amaranths depends on species-specific growth characteristics rather than on general assumptions about the genus.

The study also concludes that evaluation methods based only on plant height or visual vigor are insufficient for determining actual production potential in leafy vegetables. A species may establish rapidly during early growth stages without maintaining the canopy development required for maximum biomass production at harvest. Therefore, integrated assessment using growth rate, Leaf Area Index and final yield provide a more accurate basis for identifying high-performing indigenous vegetable species.

6.2 Recommendations

6.2.1 Recommendations to Smallholder Farmers and Vegetable Producers

Smallholder farmers producing indigenous leafy vegetables should prioritize the cultivation of *Amaranthus hybridus* for commercial leaf production because it maintained stronger canopy development and produced higher biomass yield under the tested conditions. Farmers targeting quick household vegetable supply over short production cycles can integrate *Amaranthus viridis* due to its rapid early growth. Farmers should avoid allocating large production space to *Amaranthus spinosus* for leaf biomass production unless the purpose is seed preservation or mixed indigenous vegetable diversity.

Farmers practising backyard or nutrition gardening should establish separate species plots instead of mixing wild Amaranthus species during production. This will improve management uniformity and allow better monitoring of canopy development, spacing and harvesting schedules according to the growth behaviour of each species.

6.2.2 Recommendations to Agricultural Extension Officers (AGRITEX)

AGRITEX officers in vegetable-producing districts should incorporate species-specific indigenous vegetable training into farmer field schools and ward-based demonstrations in the next production season. Training sessions should clearly distinguish the growth and yield differences among *Amaranthus viridis*, *Amaranthus spinosus* and *Amaranthus hybridus* instead of treating wild amaranths as one uniform crop group.

Extension officers should also introduce practical farmer demonstrations on canopy management and plant spacing because the study established that canopy development strongly influences final biomass yield. Demonstration plots should specifically show farmers how leaf area expansion affects productivity in leafy vegetables.

6.2.3 Recommendations to Research Institutions and Universities

Agricultural research institutions such as the Department of Research and Specialist Services (DRSS) and universities should conduct multi-location trials on wild Amaranthus species across different agroecological regions in Zimbabwe within the next three to five years. This is

necessary to determine whether the growth and yield patterns observed under Chegutu conditions remain stable under different rainfall, soil and temperature conditions.

Researchers should also develop species-specific agronomic packages for high-performing wild Amaranthus species, including spacing requirements, nutrient recommendations and harvesting intervals. Current indigenous vegetable research focuses heavily on nutritional value whilst limited attention is given to production efficiency and canopy performance.

6.2.4 Recommendations to Seed and Indigenous Vegetable Promotion Programmes

Community seed banks, nutrition gardens and indigenous vegetable promotion programmes should begin preserving and multiplying identified high-performing wild Amaranthus species separately rather than grouping all wild amaranths together. Priority multiplication should focus on *Amaranthus hybridus* because of its stronger biomass production potential.

Organisations promoting climate-resilient crops should include species identification training during seed distribution programmes so that farmers can correctly identify productive species in the field. This will reduce random selection of low-performing species during cultivation.

6.3 Recommendations to Future Researchers

Future studies should measure dry biomass accumulation, nutrient composition and regrowth ability after repeated harvesting in wild Amaranthus species. This will provide a more complete understanding of their suitability for commercial vegetable production and household nutrition systems.

Future researchers should also investigate how fertiliser application and plant density influence Leaf Area Index and biomass yield in *Amaranthus hybridus* under Zimbabwean field conditions. This will help develop practical management guidelines for improving indigenous vegetable productivity.

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APPENDICES

Appendix 1: ***GenStat Output for Growth Rate***

Analysis of variance

Variate: GROWTH_RATE

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.0913556	0.0456778	67.39	
BLOCK.*Units* stratum					
SPECIES	2	0.1008222	0.0504111	74.38	<.001
Residual	4	0.0027111	0.0006778		
Total	8	0.1948889			

Tables of means

Variate: GROWTH_RATE Grand mean 1.1189

SPECIES	A.Hybridus	A.Spinosus	A.Viridis
	1.2367	0.9800	1.1400

Least significant differences of means (5% level)

Table	SPECIES
rep.	3
d.f.	4
l.s.d.	0.05902

SPECIES

	Mean	
A.Spinosus	0.980	a
A.Viridis	1.140	b
A.Hybridus	1.237	c

*Appendix 2**: GenStat Output for Leaf Area Index (LAI)***

Analysis of variance

Variate: LAI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.1472667	0.0736333	169.92	
BLOCK.*Units*stratum SPECIES	2	0.1134000	0.0567000	130.85	<.001
Residual	4	0.0017333	0.0004333		
Total	8	0.2624000			

Tables of means

Variate: LAI

Grand mean 1.0900

SPECIES	A.Hybridus	A.Spinosus	A.Viridis
	1.2100	0.9400	1.1200

Least significant differences of means (5% level)

Table	SPECIES
rep.	3
d.f.	4
l.s.d.	0.04719

SPECIES

	Mean	
A.Spinosus	0.940	a
A.Viridis	1.120	b
A.Hybridus	1.210	c

28 DAP

Analysis of variance

Variate: LAI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.653400	0.326700	204.19	
BLOCK.*Units* stratum					
SPECIES	2	1.859400	0.929700	581.06	<.001
Residual	4	0.006400	0.001600		
Total	8	2.519200			

Tables of means Variate:

LAI Grand mean 2.890

SPECIES	A.Hybridus	A.Spinosus	A.Viridis
	3.420	2.310	2.940

Least significant differences of means (5% level)

Table	SPECIES
rep.	3
d.f.	4
l.s.d.	0.0907

SPECIES

	Mean	
A.Spinosus	2.310	a
A.Viridis	2.940	b
A.Hybridus	3.420	c

*Appendix 3**: GenStat Output for Fresh Biomass Yield***

Analysis of variance

Variate: YIELD

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.021067	0.010533	7.18	
BLOCK.*Units* stratum					
SPECIES	2	0.376067	0.188033	128.20	<.001
Residual	4	0.005867	0.001467		
Total	8	0.403000			

Tables of means Variate:

YIELD Grand mean

0.777

SPECIES	A.Hybridus	A.Spinosus	A.Viridis
	1.007	0.510	0.813

Standard errors of differences of means

Table	SPECIES
rep.	3
d.f.	4
s.e.d.	0.0313

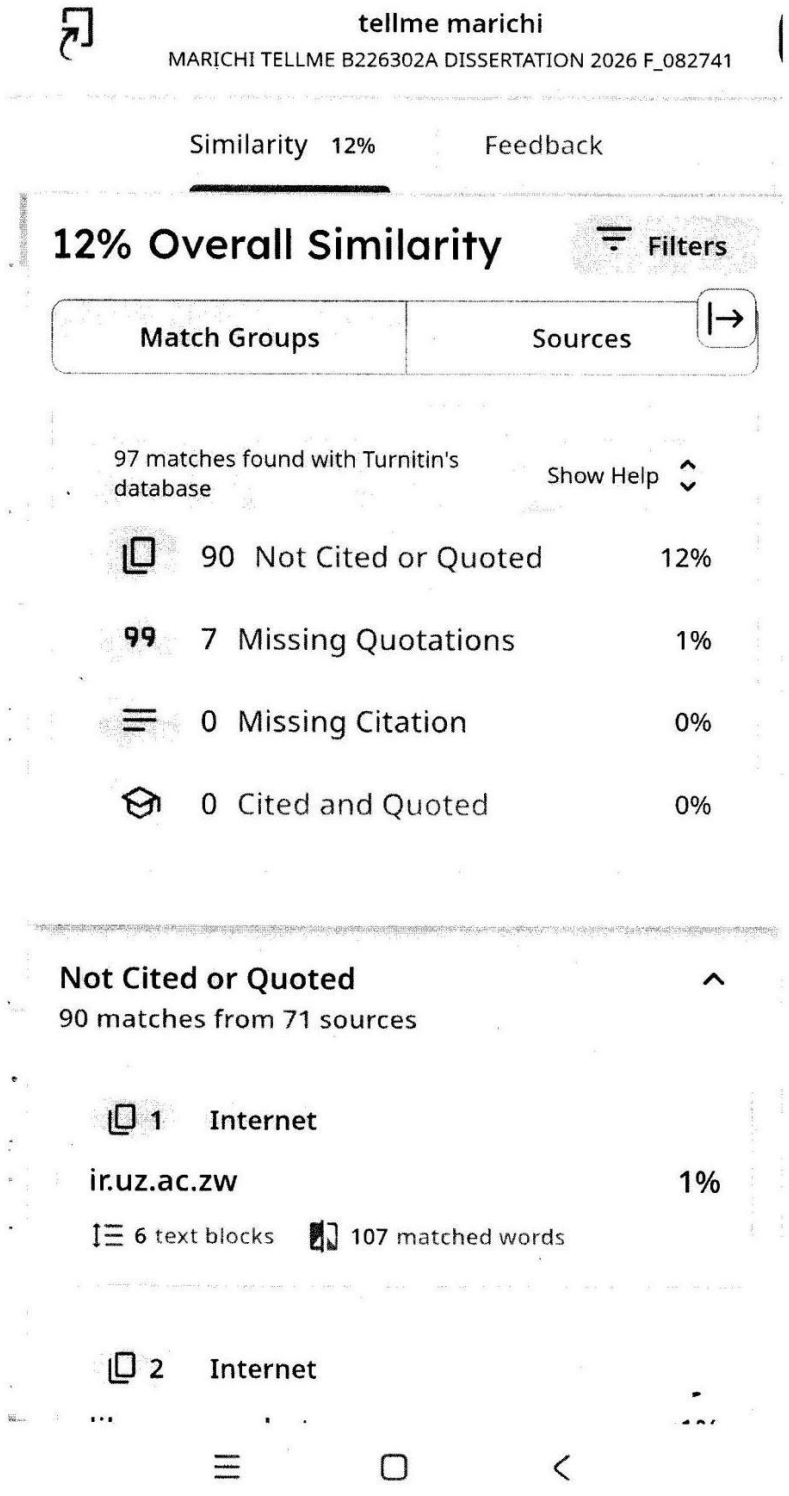
Least significant differences of means (5% level)

Table	SPECIES
rep.	3
d.f.	4
l.s.d.	0.0868

SPECIES

Mean

A.Spinosus	0.5100	a
A.Viridis	0.8133	b
A.Hybridus	1.0067	c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