PHENOTYPIC CHARACTERIZATION AND EVALUATING THE RESPONSE OF SWEETPOTATO GENOTYPES FOR DROUGHT TOLERANCE AS AN ADAPTATION TO CLIMATE CHANGE IN ETHIOPIA

SELAMAWIT ABEBE GITORE (Msc. PLANT BREEDING)

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DECLARATION

I Selamawit Abebe Gitore declare that this thesis is my original work and has not been presented for the award of a degree in any other university or any other award.

……………………………………….……………… ……………………

SELAMAWIT ABEBE GITORE **Date**
REG. NO: (A99F/26501/2018)
Department of Agricultural Science and Technology

Supervisor's approval

We confirm that the work reported in this thesis was carried out by the candidate under our supervision and has been submitted with our approval as university supervisors.

1) …………………………… ……………………

Dr. Benjamin O. Danga **Date**
Department of Agricultural Science and Technology
Kenyatta University

2) ……………………………. ……………………..

Dr. Sylvia Henga **Date**
Department of Agricultural Science and Technology
Kenyatta University

3) …………………………… ………………………

Dr. Fekadu Gurmu **Date**
Ethiopia's Southern Agricultural Research Institute
(SARI), Hawassa

DEDICATION

With great pride, I dedicate my dissertation to my son, Brooke Teketel Tadesse and my parents, as well as everything else I do. The entire family provided me with the tools and values I needed to get to where I am now.

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LIST ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
ARC	Agriculture Research Center
AVRDC	The Asian Vegetable Research and Development Center
CIP	The International Potato Centre
CSA	Central statistical Authority
DPSVs	Dual-purpose sweet potato varieties
LLN	Leaf Lobe Number
MLS	Mature Leaf Size
OFSP	Orange Fleshed Sweet Potato
PCA	Principal Component Analysis
PT	Plant Type
PTL	Petiole Length
PTPG	Petiole Pigmentation
RFC	Root Flesh Colour
RPC	Root peel colour
RS	Root shape
SP	Sweet Potato
TW	Twinning
UPGMA	Unweighted Pair Group Method of Arithmetic averages
VID	Vine Internodes Diameter

VIL	Vine Internodes Length
VIP	Vine Pigmentation
VTP	Vine Tip Pubescence

ABSTRACT

Sweet potato plays a major role as a food security crop in many countries particularly in the sub-Saharan Africa and Asia. Despite its importance, current identification is still limited, which is one of the reasons for low sweet potato productivity at the moment. Drought susceptibility is perceived as one of the major drawbacks of orange fleshed sweet potato genotypes that have been so far released. The objectives of this study are; to characterize sweet potato genotypes present in Ethiopia for selection of those possessing optimal dual-purpose characteristics, to assess the drought stress tolerance of orange-fleshed sweet potato genotypes and to identify sweet potato cultivars with good yield and quality, and assess various drought stress tolerance selection indices and choose the appropriate ones for use in identifying drought tolerant sweet potato cultivars in Ethiopia. The experiment was conducted at Boloso sore district, Wolaita region, and southern parts of Ethiopia. 40 selected sweet potato genotypes advanced from crossing experiment and 10 orange fleshed sweet potato genotypes planted on the field using Alpha lattice design for characterization and drought evaluation experiment. Characterization of the genotypes performed using international potato center standardized morphological descriptors. Classification of dual-purpose use varieties was done according to Leon- Velarde approach, based on root to vine ratio. Parameters related with a storage root yield such as vine length, vine Internode length, vine internode diameter, number of branch, vine fresh weight, root yield, Leaf area index were collected for drought evaluation study. The generated data in this study were subjected to analysis of variance using R software, agricolae package. The significantly different means were compared using tukey test at the level of $p < 0.05$. Principal component analysis and cluster analysis performed to separate and group the genotypes based on their differences and similarities. Phenotypic variability observed among the 40 genotypes for almost all leaf, vine and root parameters except for central leaf lobe, petiole length, and root thickness. The research finding showed that 30 genotypes out of 40 qualified for dual-purpose based on their index value of root to vine ratio. The study revealed that the genotypes MUSG014065-21-13, MUSG014065-21-14 and MUSG014019-7-50 showed the lowest rank sum and standard deviation of rank sum and considered as a drought tolerant genotypes. Stress tolerance index, geometric mean productivity, yield index, stress intensity index and tolerance indices were shown to be the best in identifying drought tolerant genotypes based on their strong correlation with yield under stress conditions. Efforts should be made to promote the adoption of these dual-purpose sweet potato genotypes among farmers to enhance the economic and nutritional benefits of sweet potato cultivation. Further research could also be conducted to identify the molecular markers associated with drought tolerance in sweet potato genotypes to facilitate marker-assisted selection in breeding programs. Moreover, collaboration between researchers, farmers, and policymakers is essential to promote the adoption of drought-tolerant sweet potato varieties and support sustainable agricultural practices.

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Sweet potato (*Ipomoea batatas (L.) Lam*) is a major food and feed crop in Sub-Saharan Africa and Asia, as well as an important food security crop. Sweet potato is the world's seventh most significant food crop after wheat, rice, maize, potato, barely, and cassava (Jan *et al*, 2015; CIP, 2017). The crop is well-known for its drought tolerance. However, drought, which is currently a global concern restricting agricultural output, continues to stymie its progress. As a result, drought stress is one of the most serious and widespread abiotic stresses reducing agricultural productivity around the world as a result of climate change (Blum, 2002). It is especially critical in nations where rain-fed agriculture is practiced, such as Ethiopia. Drought linked with climate change and unpredictable pattern of rainfall in Africa and increasing population pressure need advanced adaptation strategies/techniques to address food shortage and the crop yield failure.

Globally, the impacts of climate change on agriculture are becoming increasingly evident. Droughts, floods, and extreme weather events are leading to significant yield losses, which are affecting food security and economic development (IPCC, 2014). Ethiopia is one of the countries that heavily rely on sweet potato for food and income. However, the country's sweet potato production is also threatened by climate change-induced droughts. According to a report by the Intergovernmental Panel on Climate Change (IPCC), Ethiopia is expected to experience more frequent and severe droughts in the future, which could lead to a decline in sweet potato yields and threaten food security. Therefore, developing drought-tolerant sweet potato varieties is crucial for adapting to climate change in Ethiopia. In terms of climate change adaptation in Ethiopia, the government has developed several policies and initiatives to support climate resilient agriculture. For example, the Climate Resilient Green Economy (CRGE) strategy, launched in 2011, aims to build the resilience of agricultural systems to climate change and promote sustainable land use practices. The government has also established the Ethiopian Institute of Agricultural Research (EIAR), which conducts research on crop breeding and adaptation to climate change (Paul & Weinthal, 2019).

Sweet potato is Ethiopia's second-best sustainable and vital root crop after Enset or false banana [*Enseteventricosum (Welw.) Cheesman*] (CSA, 2010 & 2011). The crop is mainly and widely grown in the two regional states Debub/southern and Oromia regions. The production and productivity of sweet potato in the Debub/southern regions are mainly concentrated on three zones: Wolayta, Sidama, and Gamo gofa. The two zone's; Wolayta and Gamo gofa zones in particular are well-known for their sweet potato cultivation, and inhabitants in these zones are heavily reliant on sweet potato for food security during the famine and drought season including using the crop as a forage (Belehu, 2003; Tadesse, 2006; Tofu *et al.,* 2007 & Tesfaye, 2010). In the lack of strong non-farm pull factors, the problem of rising rural population and intergenerational division of agricultural land has resulted in Increased in rural poverty, drought due to climate change, food insecurity and environmental depletion in the study region as well as the country (Ayele, 2008). Therefore, because of a shortage of land, most smallholder farmers practice mixed farming. There is abundant proof in these regions particularly in small holder farmer’s households that the amount of livestock fodder available is in-adequate in terms of both quality and quantity (Nyaata *et al.,* 2000). In addition its production and productivity have dropped in recent years due to a lack of sufficient planting materials at the start of the rainy season, disease, and severe pest infestation, and its production and yield potential is below the world average in Ethiopia (CSA, 2019).

Sweet potato is commercially propagated through its vine; hence a high-quality vine and in sufficient quantity is required to ensure strong crop stands (Setimela *et al.*, 2004). However, a shortage of planting material is a major impediment to its production (Belehu, 2003), and vine suppliers including locals and research centers sometimes run out of planting material as the rainy season approaches (Namanda *et al*., 2013). Ethiopian farmers encounter comparable difficulties in obtaining the maximum yield of sweet potatoes due to limited resources such as land, capital, and factors such as pests, diseases, and weather patterns that can affect crops.

The shortage of arable land limits farmers' ability to produce enough sweet potatoes to meet demand. Furthermore, a lack of financial resources impedes investment in necessary inputs such as irrigation systems, fertilizers, and improved seed varieties. Biotic factors such as pests and diseases and abiotic factors such as soil degradation, drought, and uncertain weather patterns also limit the productivity of sweet potato crops.

As a result, now days the dual-purpose sweet potato has become a popular crop in maize-based farming systems, where it can be cultivated in the off-season to ensure food security during the famine time (Claessens *et al.,* 2008). Because feed is becoming increasingly limited and scarce, its vines are also utilized as cattle feed. The socioeconomic factors that are affecting sweet potato production in Ethiopia include;

restricted agricultural area, a lack of quality and suitable and sufficient planting material and poor agronomic management practices (Fekadu *et al.,* 2015).

In the sweet potato germplasm development agenda for food security and poverty reduction, the production of dual-purpose varieties has acquired attention (Andrade *et al.*, 2009). Sweet potatoes have been categorized into four groups based on their genetic potential to distribute nutrients to forage and roots using the root to vine biomass ratio (Leon-Velarde, 2000). In Ethiopia, breeding efforts have concentrated on roots for food, and while a number of genotypes have been introduced, no information on the dual-purpose characteristics of these cultivars available.

Therefore, developing and producing dual purpose sweet potato genotypes which is capable of producing large stored root and aboveground biomass yields is very crucial. Sweet potato is economically feasible and viable as evidenced by comparatively high and total yield production, and the fodder's crude protein content that boosts milk output and profitability (Andrade *et al.,* 2009). The crop is drought resistant and grows in a short period makes it ideal in order to adapt to climate change extremes during current times of global warming (Mwanga *et al.,* 2011).

The Wolaita Zone, located in the southern region of Ethiopia, is known for its frequent food shortages and susceptibility to famine. The area has a significant population but is limited in terms of available land. Additionally, the region is highly vulnerable to drought, as noted by Ayele in 2008.Although the Wolaita region is the highest sweet potato production zone in Ethiopia, different sweet potato production constraints were identified (Ahmed, 2017). According to a study by Fekadu, *et al.,* (2015) the major sweet potato production constraints in this zone are heat and drought at 21.6% which had a larger percentage compared to other factors such as lack of sweet potato propagating materials (20.1%), lack of farmland (15.7%) and diseases and pest (10.0%). Other important constraints include land degradation, poor soil fertility, restricted availability, poor quality of seeds, high reliance on rainfall, and fertilizers (Njeru *et al.,* 2016; Yimer & Babage, 2018). These issues are mainly exacerbated because there is a high rapid population increase and environmental degradation. Therefore, adaptation strategies or suitable management solutions are urgently required to reduce the constraints and increase agricultural productivity without jeopardizing the potential of future generations (Asfaw & Lipper, 2012).

Improving agricultural productivity and crop efficiency to give a good yield under different environmental conditions is an important element of Sub-Saharan Africa's (SSA's) development agenda. There is a requirement for alternative adaptation approaches/strategies to deal with guaranteeing food shortages. These kinds of solutions must be consistent, sustainable, and resilient and of applied solutions towards confronting smallholder farmers such as drought stress related to climate change extremes and weather variability. Adopting climate-smart agriculture is the finest and most viable method for reforming and reorienting agricultural expansion in light of the new realities of climate change. The fundamental goals of climate-smart agriculture are food and nutrition security and agricultural development, with productivity/crop enhancement, adaptation, and mitigation recognized as the three interrelated pillars required to reach this goal (FAO, 2013 & Lipper *et al.,* 2014). Farmers' in particular smallholder farmers' vulnerability to short-term climate change risks is reduced while their resilience for adaptation is improved by boosting their ability to adapt and prosper in the face of climate change hazards and longer-term challenges, according to the approach adaption. The word ‘‘adaptation’’ comprises the actions of altering agricultural practices, processes, and smallholder farmers' income to react to the real risk of climate change (Harvey *et al*., 2018).When it comes to agricultural practices, there are several techniques that can be employed to adapt to and mitigate the effects of climate change. Some of these techniques include altering agricultural inputs, such as selecting cultivars that are better suited to withstand heat and drought shock. Additionally, water harvesting and soil moisture conservation practices can be extensively used to optimize yields. Management of rainwater can also help to prevent nutrient leaching, water logging, and soil erosion during times of high rainfall. Lastly, changing the timing or location of cropping activities can also be beneficial. Overall, there are many possible techniques that can be employed to optimize agricultural practices in the face of climate change. In systemic actions, such as diversifying livelihoods against climate change risks and an institutional transformation to create encouragements for enhanced resource management.

Identifying and improving neglected/underutilized crops for drought tolerance is the greatest adaptation strategy to reduce climate change vulnerability and risk (Mabhaudhi, 2009). Sweet potato is one of the crops which are the most adaptable mainstay for addressing the challenges of food insecurity related for millions of people and producing more food per unit area of land. Cereals are, in most situations, the cheapest source of sustenance for many people. Alternative main foods, particularly sweet potato (*Ipomoea batatas*), have been sought as the region's population has grown and farm holdings have shrunk (Chauvin *et al.*, 2012).

Neglected/underutilized crops play an important role in ensuring and fulfilling future food security. Most neglected crops such as root crops are highly nutritious and highly adaptable to varied environmental conditions. They can be utilized as direct alternative crops to help farmers make money in drought-prone areas, as well as indirectly as genetic resources conservation for agricultural improvement in breeding programs. Studying genetic diversity is crucial, particularly as an adaptation strategy to climate change. Orange fleshed sweet potato (OFSP) genotypes are particularly nutritious, and they are believed to be the primary contributors to the sweet potato's nutritional value due to their high concentration of Β-carotene, which is a precursor for Vitamin A. Therefore, OFSP genotypes play a significant role in addressing Vitamin A deficiency and improving food security. In light of this, evaluating OFSP genotypes for their ability to withstand drought stress is the best approach to addressing the challenges that arise during sweet potato production. Overall, studying genetic diversity, with a focus on OFSP genotypes, is an important strategy to combat the effects of climate change on sweet potato production and improve food security.

1.2 Statement of the problem

The scarcity of land, capital, and other biotic and abiotic factors that Ethiopian farmers face hampers their efforts to maximize crop productivity (Taffese *et al.,* 2011; Bakabil, 2014). This presents a major challenge to food security in Ethiopia. One solution to this problem is to develop dual-purpose sweet potato cultivars that can provide significant stored root and above-ground biomass production. These cultivars can be used not only for food, but also for animal feed and as a source of renewable energy. By focusing on the development of such genotypes, farmers can increase their productivity and meet the growing demand for food and other agricultural products. There has been limited information on the morphological characterization of sweet potato varieties suitable for both human consumption and livestock feed. In Ethiopia, 26 sweet potato cultivars have already been released, with six of them being OFSP. Despite their importance, OFSP genotypes are drought susceptible. The vast majority of the research has focused on agronomy and seed systems, with the ultimate goal of improving vitamin A status and virus disease resistance in households. Improving this crop to make it more drought resistant is a vital and important method for meeting national food demands. There has been limited research into the water stress tolerance of OFSP genotypes. Despite the fact that drought stress is the most important hazard to OFSP production, progress in producing drought-resistant genotypes is hampered by a lack of adequate selection criteria.

1.3 Justification

The significance of the study lies in addressing the challenges that Ethiopian farmers face due to the scarcity of land, capital, and other biotic and abiotic factors, which limit their efforts to maximize crop productivity. The development of dual-purpose sweet potato cultivars that can provide significant stored root and above-ground biomass production presents a solution to this problem. By developing such genotypes, farmers can increase their productivity and meet the growing demand for food and other agricultural products. The study is particularly significant because there has been limited information on the morphological characterization of sweet potato varieties suitable for both human consumption and livestock feed. Furthermore, although there are already 26 sweet potato cultivars released in Ethiopia, with six of them being OFSP, these genotypes are still susceptible to drought stress, which is the most significant hazard to OFSP production. Therefore, improving the crop to make it more drought-resistant is a vital method for meeting national food demands. However, progress in producing drought-resistant genotypes is hampered by a lack of adequate selection criteria, which is why this study's focus on the water stress tolerance of OFSP genotypes is significant. Overall, the study's findings can contribute to improving food security in Ethiopia by developing drought-resistant sweet potato genotypes suitable for both human consumption and livestock feed, providing a source of renewable energy, and increasing agricultural productivity.

1.4 Objective of the study

1.4.1 General Objectives

The broad objective of the study is to characterize sweet potato genotypes and classify them as dual-purpose, and to evaluate the response of OFSP genotypes to various drought stress environmental conditions using morphological traits.

1.4.2 Specific objectives

i. To morphologically characterize 40 sweet potato genotypes and select the ones with optimal dual-purpose traits to be used as a parent in future breeding programs, in the Wolaita zone of Ethiopia.

ii. To evaluate the effect of drought stress conditions on yield and quality of orange-fleshed sweet potato genotypes.

iii. Assess various drought stress tolerance selection indices and choose the appropriate ones for use in identifying drought tolerant sweet potato cultivars in Ethiopia.

1.5 Research hypotheses

The hypotheses that were examined through the research can be stated as follows:

I. **H1**: There is a significant difference in vine, leaf, and root characteristics among the 40 tested sweet potato genotypes.

II. **H1**: There are high levels of tolerance present in the tested sweet potato genotypes.

III. **H1**: The selected drought stress tolerance selection indices are effective in identifying drought-tolerant sweet potato genotypes.

1.6 Significance of the study

This study information can be useful in the selection and breeding of sweet potato genotypes that are better suited for the local environment and can contribute to the development of the sweet potato industry in Ethiopia. The identification of cultivars with good yield and quality under drought stress can help mitigate the negative impact of drought on sweet potato production and enhance food security in Ethiopia. The appropriate selection indices can be useful in developing breeding strategies for sweet potato cultivars that are more resilient to drought conditions, ultimately leading to increased productivity and food security. Overall, the study's significance lies in contributing to the development of sweet potato cultivars that are better suited to the local environment and can withstand harsh environmental conditions such as drought, ultimately leading to sustainable agriculture and improved food security in Ethiopia.

1.7 Conceptual framework

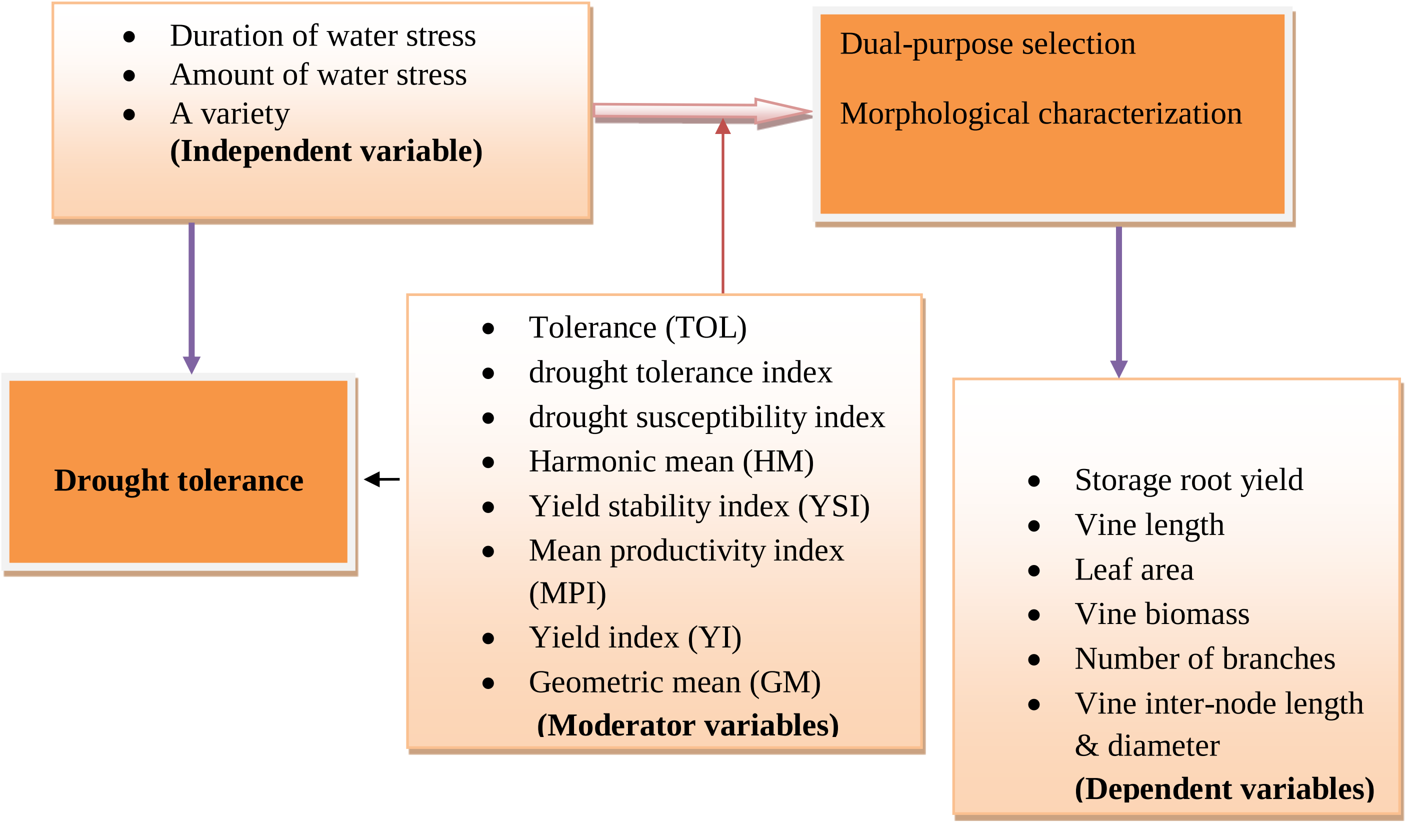

Figure 1.1 Conceptual framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Sweet potato botanical description

Sweet potato (*Ipomoea batatas*) is a starchy, bulky crop and tuberous root vegetable that belongs to the Convolvulaceae family. It is a dicotyledonous plant that is indigenous to Central and South America, and domesticated sweet potatoes were first discovered in Central America around 5,000 years ago. The crop is similar to the potato (Solanum tuberosum), as they both belong to the Solanales order, and the sweet potato's leaves and shoots can also be consumed as greens. The sweet potato vine is a herbaceous perennial with alternate palmately/heart-shaped lobed leaves, medium-sized flowers, and tuberous roots that come in a variety of colors, including yellow, orange, red, brown, purple, and beige. The flesh of sweet potatoes also varies in color and can be white, red, pink, violet, yellow, orange, and purple.

White or pale yellow flesh sweet potato is less sweet and moist than red, pink, or orange flesh sweet potato, and sweet potatoes are a good source of dietary fiber, beta-carotene (a carotenoid of vitamin A), complex carbs, and micronutrients such as manganese, vitamin B5, and vitamin B6. Sweet potato cultivars that contain more beta-carotene than light-colored flesh cultivars are recommended in areas where vitamin A deficiency is a serious concern.

2.2 Cultivation of sweet potato

Sweet potatoes (*Ipomoea batatas*) are bulky, starchy crops with sweet tuberous roots that belong to the morning glory family, Convolvulaceae (Purseglove & John, 1968; Woolfe & Jennifer, 1992). They are indigenous to Central and South America, with domesticated sweet potatoes first discovered in Central America at least 5,000 years ago. The crop bears alternate palmately/heart-shaped lobed leaves and is an herbaceous perennial vine with regular, medium-sized flowers. Sweet potatoes come in various colors, including yellow, orange, red, brown, purple, and beige, with flesh colors that can range from white, red, pink, violet, yellow, orange, and purple (Leobenstein & Thottappilly, 2009).

In addition to simple starches, sweet potatoes are also rich in dietary fiber, beta-carotene (a carotenoid of vitamin A), complex carbs, and micronutrients such as manganese, vitamin B5, and vitamin B6 (USDA, 2013). Growing sweet potato cultivars that contain more beta-carotene than light-colored flesh cultivars is recommended in areas where vitamin A deficiency is a serious concern.

Sweet potatoes are mostly grown in regions between 40° N and 20° N latitudes, accounting for roughly 70% of total global production. They are also grown between 10° S and 15° N, accounting for around 24% of global production (Hijmans *et al.*, 2001). According to FAO (2013), the crop can be grown year-round in both tropical and subtropical climates, as well as in warm temperate climates. It can also be grown in locations where cultivation is limited to the summer season.

Sweet potatoes grow best at temperatures between 24 °C (75 °F) and 30 °C (86 °F), with enough sunshine and mild nights (moderate temperature), and do not tolerate frost or water logging, which cause tuber rots and shrink storage root development (Ahn, 1993). The ideal temperature range for the vegetative process is 20 to 25°C. The highest yields are obtained when daytime temperatures are high (25 to 30 ° C) and nighttime temperatures are low (15 to 20°C) (FAO, 2013). Low temperatures at night stimulate tuber production, while high temperatures during the day favor vegetative growth. Sweet potatoes require a minimum of 500mm of rain in the growing season, with a rainfall requirement of 750–1,000 mm every year. The plant is quite sensitive to drought during the tuber start stage, 50-60 days after planting (FAO, 2013).

Plants that thrive on short days, like sweet potatoes, require a lot of light. A short day, photoperiod, and changes in temperature affect the root tubers' growth. The crop grows best in soils with a depth of over 25 cm and good surface and internal drainage. Ferritic, brown humic, and calcimorphologic soils provide the best results (Woolfe, 1992). The best soil for growing sweet potatoes is slightly acidic or neutral with a pH level between 5.5 and 6.5. Bacterial infections thrive in very acidic or alkaline soils, and yields suffer as a result (Mortley *et al.*, 1991). The crop is commonly grown on 1 m apart mounds and elevated beds, and root growth and sweet potato root bulking are improved by deep culture/ deep plowing or tilling the soil to create a deeper and looser soil structure.

Sweet potato is considered as the second most significant root crop in Ethiopia, next to enset, and it plays a crucial role in providing a well-balanced diet to a large number of individuals across the country (Fekadu *et al.,* 2015). It is also commonly used as an integrated crop with animals in farming systems (Belehu, 2003). However, the mean storage yield of sweet potato in Ethiopia is poor, with an average of around 8 t/ha, which is considerably lower than the productivity of 30 – 73 t/ha and the global average of 14.8 t/ha (Belehu, 2003; Kivuva *et al.,* 2014).

2.3 Constraints to Ethiopia's sweet potato production

Sweet potato production is hindered by various factors, including biotic and abiotic stressors, as well as socioeconomic factors. Studies by Kapinga and Carey (2003) and Ndunguru *et al.* (2009) have revealed that biotic stressors such as diseases, insect pests, and weeds, and abiotic stressors such as recurrent drought, heat shock, and inadequate soil fertility, have a significant impact on sweet potato storage tuberous root yield production. Fekadu *et al.* (2015) noted that a lack of improved sweet potato cultivars, low dry matter content in orange-fleshed sweet potato (OFSP) cultivars, a lack of planting materials, and low β-carotene content in white-fleshed sweet potato variations are all socio-economic aspects to consider. In Ethiopia, the main sweet potato cultivation restraints are heat and drought, according to Fekadu *et al.* (2015).

Multiple studies have shown that climate change-induced drought stress is a significant abiotic limitation on sweet potato productivity, particularly in tropical heat (Bennett, 2003; Amede *et al.,* 2004). The shortage of moisture in the soil due to drought is a significant abiotic restraint to crop production (Amede *et al.,* 2004; Claessens *et al.,* 2012), and it worsens when climate change intensifies. Drought stress decreases yield by reducing photosynthesis and translocation of assimilates (Anselmo *et al.,* 1998; Anjum *et al.,* 2011). Therefore, breeding crops for drought tolerance can potentially guarantee greater yield production in water shortage conditions (Sorrells *et al.,* 2000).

Another main constraint for sweet potato production in Ethiopia is the shortage of planting materials (Ahmed, 2017). Limited visits by extension officers and training to only a few sweet potato growers each season have caused farmers to undervalue or underestimate the crop's importance, resulting in hesitancy to plant it.

2.4 Sweet potato: A nutritious and versatile staple crop for food and nutrition security

Sweet potato is considered one of the most significant staple and nutritious foods globally due to its various benefits and applications that contribute to food security, particularly in developed countries (Kivuva *et al.,* 2014). Sweet potatoes are widely consumed in Africa, Asia, the Caribbean, and South America due to their high carbohydrate content, as well as being rich in vitamins A and C, fiber, iron, potassium, and protein (Bovell-Benjamin, 2007; Kaur & Sandhu, 2016). This crop has the potential to meet the nutritional needs of disadvantaged farming communities since it is a versatile and tasty vegetable that is highly nutritious. Sweet potatoes rank as the seventh largest food crop after maize, rice, wheat, potatoes, cassava, and barley. Sweet potatoes may not be the most nutritious staple crop compared to cereal crops. However, studies have shown that sweet potato leaves and vines are highly nutritious vegetables, containing high levels of protein, vitamins, anthocyanins, and minerals (Islam, 2006). Sweet potato roots, whether fresh, cooked, uncooked, sun-dried, or fermented as silage, are sometimes used to improve other cereal feed ingredients, particularly maize (Mangwe *et al.,* 2016). In contrast to accessions and clones cultivated only for roots or fodder production, dual-purpose sweet potatoes provide food for humans, feed for animals, and contribute to the family's diet, health, and household income.

Additionally, sweet potato roots are a good source of soluble fiber, carbohydrates, and various vitamins and minerals such as vitamins B, C, B6, riboflavin, and E, as well as manganese, potassium, calcium, iron, copper, magnesium, phosphorus, and zinc (Woolfe, 1992; Burri, 2011).Sweet potato storage roots are consumed fresh or boiled, and they can also be chipped, dried, and milled into flour for snacks and baby weaning foods (Engoru *et al.,* 2005a). Despite its many potential uses as a food security crop, sweet potatoes are mainly consumed fresh or used as livestock feed worldwide, with less than 1% of the total production processed as dried chips or flour, primarily for home consumption. However, China is an exception, with around 15% of its sweet potato crop used for commercial starch, noodles, and snack food production (Mangwe *et al.,* 2016).

Sweet potato's leaves and vines are rich in nutrients, containing 11% crude protein and 50% organic matter digestibility (Mutimura *et al.,* 2015). Fodder-based diary production has been observed to increase mean milk yield by about 1.5 liters per day due to the high nutritional content of the crop's above-ground biomass, and as a result, farmer-preferred dual-purpose sweet potato varieties (DPSVs) are required in crop-livestock mixed farming systems to increase storage root and above-ground biomass outputs (Peters, 2008).

The consumption of all parts of the sweet potato plant is important according to Woolfe (1992). The top three starchy root crops consumed worldwide per capita are potato, cassava, and sweet potato, with sweet potato ranking third at 8.3 kg per capita, after potato at 32.6 kg and cassava at 14.3 kg, as reported by Mangwe *et al.,* (2016). This highlights the significant role that sweet potatoes play in global food consumption, and the need to utilize all components of the plant to maximize its nutritional benefits. Sweet potato is a widely consumed food in Ethiopia, commonly cooked or mashed. Orange-fleshed sweet potato varieties are particularly encouraged in Sub-Saharan Africa as they contain high levels of beta-carotene, a precursor of vitamin A, which can help combat vitamin A deficiency. Moreover, sweet potatoes have a low glycemic index, making them suitable for diabetics as they can help stabilize blood sugar levels and prevent insulin resistance. Sweet potato roots and leaves are also a good source of protein and other essential nutrients, making them a beneficial food for both humans and livestock. Additionally, sweet potato has been found to have anti-cancer, anti-diabetic, and anti-inflammatory properties. Interestingly, sweet potato can also be used as a natural food coloring agent, as it contains high levels of anthocyanin and beta-carotene with excellent color extract stability (Tumwegamire & Ndunguru, 2006; Woolfe, 1992; Mais & Brennan, 2008; Antia *et al.,* 2006).

In summary, sweet potato is a versatile and nutritious crop that has the potential to address various health challenges and nutritional deficiencies in developing countries, especially in Sub-Saharan Africa

2.5 Sweet potato's potential as a livestock feed

In Africa, according to Woolfe's study in 1992; Bovell-Benjamin, 2007; Dash & Rayaguru, 2019, there is limited information available regarding the use of sweet potato for animal feed. Although nearly all the roots are consumed by humans, the damaged ones are given to livestock. Sweet potato is considered a favorable fodder due to its high calorie and protein content from the tubers and vines, as well as its palatability. Thus, the vines, crop residues, and unmarketable roots are primarily used for livestock feed. Sweet potato stems are easily digestible by rumen and monogastrics, and they contain low concentrations of enzyme trypsin inhibitors, which also provide rumen biodegradable protein for microbial synthesis of proteins that is not degraded in the rumen (Murugan *et al.*, 2012).

The crop of sweet potatoes is capable of regenerating itself when harvested, through a process where the vines are harvested periodically throughout the growing season until the roots are ready to be harvested, as described by León-Velarde in 2000. Forage varieties of sweet potato that grow well on vines in sub-Saharan Africa are used as high-value fodder for dairy cows, dairy goats, and large-scale pig farming, while dual-purpose varieties can be provided to small-scale pig farmers (Larbi *et al.,* 2007). Many farmers in Asia have adopted sweet potatoes as fodder and dual-use for pig production, which increases feed availability and reduces feed costs (Claessens *et al.,* 2008). Advanced dual-purpose cultivars with high biomass yields from both roots and stems and choices for feed production are the growth and economy of small pigs that use sweet potato roots and vines as their primary pig farming feed and it May contribute to efficiency (León Velarde, 2000).

According to field research conducted in western Kenya, milk production increased after improved feed quality by using dual-use sweet potatoes, which can improve cow nutrition and milk production (Claessens *et al.,* 2008). Silage sweet potato vines and roots have been shown to increase the nutritional value of vines and roots, increase the growth rate of animals that eat them, and reduce production costs. Improved forage cultivars in East Africa will yield 35 ton per hectare of vines per season (70 ton per hectare/year with two crops) and up to 60 ton per hectare per season (120 ton per season) per hectare/year) with better conditions and management, according to sweet potato breeders CIPSSA (Peters, 2008). Forage sweet potatoes are mostly preferred by dairy cattle, dairy goats, and huge livestock farmers, while dual-use sweet potatoes with storage roots are preferred by smallholder farmers (Claessens *et al.,* 2008; Mugumaarhahama *et al.*, 2021). Sweet potatoes can be used to supplement the diets of dairy cows, goats, and pigs in place of elephant grass or other pastures (Claessens *et al.*, 2008). Year-round feed requirements are a significant obstacle in mixed systems, but sweet potatoes can be used without negative environmental impacts to meet the requirement. The findings are significant for dairy and goat farmers, as well as pig farmers who mix fodder with vines to save money and land (Herrero *et al.*, 2010).

2.6 Morphological characterization of sweet potato genotypes

The phenotypic characterization of sweet potatoes involves the assessment of various physical traits such as vine, leaf, flower, and root storage properties. This approach has been previously used to classify different varieties of sweet potatoes, as described by Huaman (1999). Additionally, this method has been employed to identify duplicate accessions, identify specific character traits, and link them to agronomical significant attributes, as outlined by Karuri *et al.* (2010).Rabara *et al.* (2014) stated that characteristic descriptors are used to define the traits that can be utilized in identifying germplasm and evaluating its potential usefulness, thereby enabling a clear differentiation among phenotypes. The standardization of descriptor lists has been crucial in establishing a uniform language for data on gene banks, which has been beneficial for sweet potato phenotypic characterization. This uniformity allows for easier comparison and identification of germplasm, and facilitates the evaluation of potential utility and genetic diversity. The use of standard descriptors has been instrumental in enabling effective collaboration among breeders, gene bank managers, and researchers in the field of sweet potato phenotypic characterization (Human *et al.,* 1991).

The phenotypic identification of plants is based on morphological traits observed in the field and it is a critical method in genotype categorization and taxonomic status study. Most agronomic traits typically controlled by numerous genes and thus are subject to varying degrees of environmental modifications and interactions, rendering them vague and of little utility in cultivar identification (Karuri *et al.,* 2010). Morphological and agronomic features, such as that of the storage root to vine ratio, are being used to define and select dual-purpose sweet potato cultivars (León-Velarde, 2000).

2.7 Dual-purpose sweet potato

Sweet potatoes have traditionally been grown primarily for tuber production, with the leaves regarded as nothing more than a waste product. The energy-dense tuber (2.6M cal of metabolizable energy/kg dry matter according to McDowell *et al* 1974 is the major reason for producing this plant, yet it only contains 3.4 percent crude protein.

The forage part of the plant is highly valuable for animal feed in the tropics due to its digestibility of over 62 percent and crude protein content of 11 percent, as evidenced by studies conducted by Backer in 1976 & Kambashi *et al.* in 2014. Thus, both components of the plant's products have become crucial. Leon-Velarde *et al.* (1997) grouped the sweet potato genotypes in to five kinds: (i) forage, (ii) low dual-purpose, (iii) high dual-purpose, (iv) low root production, and (VI) high root production. Appropriate cultivars for both low and high dual-purpose types, as well as the forage type, could be utilized if crop-livestock systems were integrated. Furthermore, sweet potato vines are suitable for animal feed due to a high crude protein content which ranges from 16 to 29 % by dry mass, making them comparable to fodder green manure plants (Klinger et al., 2020). According to Kaya &Yildirim (2011), sweet potato could also be used to boost the color of egg yolk on layer because of storage roots as well as foliage of sweet potato contain high in -carotene and xanthophylls. According to León-Velarde, 2000 the dual purpose sweet potato would also have a competitive edge over clones selected for either storage roots or fodder production (CIP Program Report, 1999-2000). It would provide human food as well as animal feed for livestock, and it would be fully connected with the livestock management system. The sweet potato's capability to regenerate can be utilized by the management system through a strategy of regularly or occasionally gathering the vines throughout the cultivation period before gathering the roots. Many researchers have studied sweet potato used for dual-purpose, including Larbi *et al.*, (2007), Etela *et al.*, (2008), Claessens *et al.,* (2008), Peters (2008), Karachi & Dzowela, (1990).

2.8 Dual purpose sweet potato varieties for dry land farming

The amount of land available for forage production diminishes as the population rises and land sizes shrink, since the remaining acreage is used to grow food crops (FAO, 2013). As a result, dual crops which could be used for either human food or feed for livestock have grown in popularity. Because of its ability to endure semi-arid climates and potential for use as both human food and livestock feed, sweet potato (*Ipomoea batatas*) has sparked the interest of a number of research groups and governments in recent years. However, because data on its contribution to livestock productivity in Sub-Saharan Africa is scarce, its potential as a livestock feed has yet to be fully recognized (Ondiek, 2000). According to tests conducted at the International Potato Centre (C1P) in

2008, farmers prefer dual-purpose cultivars because they supply adequate tubers for human use as well as cattle fodder. Dual-purpose sweet potato cultivars are highly favored as they offer flexibility in terms of harvesting time throughout the planting season. Ethiopia is among the top sweet potato producers in the world, ranked 15th with an annual production of 2,701,599 tons (Dan *et al.*, 2013). In the primary wet season, sweet potatoes occupy around 53,369 acres of land in Ethiopia. Furthermore, the country has released 26 improved sweet potato genotypes since 1990, indicating a commitment to enhancing sweet potato production (Asrat *et al.*, 2017; Aldow, 2017). These facts demonstrate the significant potential of sweet potato cultivation in Ethiopia and its importance as a major crop for the country's agricultural economy. Programs for breeding and germplasm management have focused on oromia and Southern Nations, Nationalities, and Peoples' Region (SNNPRS) Regions of Ethiopia. However, research into the possible utilization sweet potato as a food and forage is limited.

As the demand increasing at the global level for sweet tubers and feedstock increases, researchers are concentrating their efforts on developing lines that can meet all needs (Karachi, 2008). Leon-Velarde *et al.* (1997) reported that some genotypes of sweet potato have the potential to produce high amounts of stored roots and above-ground biomass that can be used for both human and livestock feed. These genotypes have shown promising results and can be utilized in crop-livestock systems. This suggests that sweet potato is a versatile and valuable crop that can meet the demands of both human and animal nutrition. Dual-purpose sweet potato cultivars have been identified by Leon-Velarde *et al.* (1997), León-Velarde, 2000, and Lukuyu *et al.* (2014). The ratio of root-to-forage dry matter yield can be used to select dual-purpose cultivars (León-Velarde, 2000). One of the agricultural advancements made in the production of sweet potato is the development of dual-purpose sweet potato varieties (DPSVs). These DPSVs are specially bred to produce both storage roots that are fit for human consumption and vines that can serve as animal feed, especially for cows. This innovation in sweet potato farming has great potential to improve food security and livestock nutrition in many areas around the world.

According to the Population Reference Bureau in Washington, Ethiopia's population is predicted to grow by 120 percent by 2050.More biomass must be produced to address the requirements for human food and livestock feed, which can be accomplished by exploiting improved genotypes and the genetic potential of crops with multiple uses. Growing dual-purpose crop kinds would make better use of natural resources, such as limited agricultural area, and would result in higher, more sustainable crop yields. In farming systems that mix crop and livestock production, increased livelihoods and resilience are frequently observed (Gibon *et al.*, 2012).

2.9 Crop variety development as an adaptation to climate change impact

Crop productivity has been negatively impacted by climate change extremes caused due to global warming. Long-term average rainfall and temperature trends, inter-annual climatic variability, phenological stage shocks, and extreme weather events all have an impact on crop production (IPCC, 2012). Different types of environmental stressors affect plant species differently at each developmental stage, and some crops are more resistant to certain types of stressors than other crops. As the climate changes, agricultural production technologies, such as irrigation, must adapt to the changing environment. Variation in precipitation variable patterns has a significant impact on crop productivity. These include average seasonal variations, duration and severity of specific precipitation events, and frequency and duration of drought (Simpson, 2017). When precipitation fluctuations are paired with temperature shifts that affect the crop's evaporative demands, the impact is amplified. Depending on the crop's phenological stage, this could result in various types of moisture stress.

Crop development is critical for enhancing agricultural productivity and ensuring food and nutrition security. Climate change is exacerbating the demand for new novel crops with greater plant diversity and plasticity. To keep up with constantly changing climate conditions, farmers must replace crop kinds with better-adapted cultivars (Porter *et al.,* 2014). Farmers must modify crop kinds throughout time and employ suitable ones to reduce climate risk as part of climate adaptation. Climate-smart agriculture necessitates the use of high-quality seeds and planting materials derived from well-adapted cultivars. According to the FAO in 2011, growing high-quality crops from old or outdated seeds is not possible. This is because the germination rate of the seeds decreases over time, which affects the growth and yield of the crops. In other words, using old or stale seeds reduces the likelihood of obtaining good quality crops. Multi-location trials are common in national, regional, and international plant breeding efforts aimed at developing crop varieties that are resistant to climate-related phenomena as well as resource-efficient in their resource use, thereby reducing their impact on the agricultural ecosystem and the wider environment. Drought resilience, salinity resistance, and flooding resistance are the most prevalent climate-related traits for which crop varieties are produced.

To adapt agricultural systems to climate change, plant breeders must develop a bigger portfolio of varieties across a wide range of crops. Obtaining heritable variants, particularly from non-adapted materials such as crop wild cousins that breeders do not generally use, will be crucial in the production of novel varieties. techniques, including pre-breeding This would necessitate the institutionalization and expansion of pre-breeding operations in which germplasm curators and breeders work together to identify carriers of desirable traits, evaluate these putative parents, and cross promising ones with elite lines to provide intermediate breeding material. Induced mutations and biotechnological procedures like genetic engineering and genome editing may also be required to produce new variations that aren't already present in the gene pool. Walter *et al.* (2012) suggest that the effectiveness of agricultural variety development techniques, such as pre-breeding, can be enhanced by utilizing advanced genotyping and phenotyping technologies. This means that by using these modern tools, scientists and breeders can more accurately analyze and select plants with desirable traits for further breeding, which can ultimately lead to the development of better crop varieties.

2.9.1 Breeding sweet potato varieties for drought stress

Underdeveloped countries, whose agricultural systems are particularly vulnerable to climatic circumstances and where even little temperature increases have a significant impact on productivity, are expected to be particularly heavily struck by global warming. According to the Food and Agricultural Organization of the United Nations, by 2025, 480 million people in Africa may be living in places with very limited water, and 600,000 km2 of land that is currently classified as moderately confined may become severely confined if climatic conditions worsen (FAOSTAT, 2009; Adhikar *et al.,* 2015). As a result, improving the efficiency of agricultural water use is crucial. An integrated water resource management strategy will be necessary to encourage efficient and equitable use of the resource, as well as to maintain sustainability

As a result, developing drought-tolerant crops is a critical step toward satisfying global food demands while conserving water. Increased scientific efforts to improve sweet potato production and consumption have resulted from a growing appreciation of the crop's immense potential as a nutrient-dense meal for people and animals (Wolfe, 1992&Yamakawa, 2002; Yue, 2004). Sweet potatoes are particularly essential in developing nations because they are a highly adaptable crop that produces huge amounts of food per unit area and unit time during brief rainy spells, giving them a competitive advantage over other staples (Mwanga *et al.*, 2011). Sweet potatoes may be planted and harvested at any time of year and tolerate high temperatures and low fertility soils.

Sweet potato is considered an easy crop to cultivate and is capable of withstanding drought during the early stages of growth, which involves the development of vines and the initiation of storage roots. However, despite its perceived hardiness, sweet potato is still susceptible to water shortages, particularly during these critical stages (Rosenthal, 2017).Drought, on the other hand, is a significant environmental obstacle for sweet potato growth in a rain-fed location. Due to limited soil water supply, different cultivars may behave differently. As a result, cultivar selection for drought resistance is emphasized. Irrigation agriculture can be an economical and effective way to mitigate the effects of drought on crop yields (Ahmed *et al.,* 2019). This method involves providing water to crops through artificial means, such as sprinkler systems or drip irrigation, to supplement natural rainfall. Farmers, on the other hand, do not have access to water or irrigation facilities. Furthermore, due to the exponential growth of the human population and present global climate change, securing clean water for irrigation is a major concern. As a result, developing and deploying drought-tolerant sweet potato varieties is the greatest long-term method for increasing sweet potato productivity. Drought tolerance breeding requires an understanding of the physiological mechanisms involved in drought tolerance, as well as its genetic regulation of yield and yield components (Subbarao *et al.*, 2000; Rahimi *et al.*, 2021).

2.10 Potential traits for drought tolerance

When water availability is a concern, the ability to maintain economic output in the face of water shortages is an important attribute. Dehydration avoidance, dehydration tolerance, and other traits associated with healthy development and metabolism under stress (Okogbenin *et al.*, 2013) can all be beneficial. Drought phenotypic features that are desirable must be genetically associated to yield under stress, highly heritable, genetically changeable, easy to assess, and stable across time. Sweet potato yields are affected by water stress timing over the growing season, as well as meteorological and soil conditions (Tourneux *et al.*, 2003). Therefore, these aspects must be addressed before giving recommendations for ideal genotypes for any particular habitat (Okogbenin *et al.*, 2013). At every stage of crop development, the morphology and architecture of the root system can affect the hydrostatic gradient.

The root system's radial (into the root) and axial (inside the xylem) resistance to water flow may be significant enough to increase the gradient, reduce hydraulic conductivity, and raise canopy temperature (Mahan *et al.*, 1995). Drought tolerance is assumed to be improved by an increased root to shoot ratio and the tendency for root growth to be sustained more than shoot growth (Jefferies, 1993). Cultivar yields can be compared after stress conditions have been applied. It serves as a selection signal because there must be a link between a resistant cultivar and yield. The leaf area, which is controlled by stem phonology, morphology, leaf size, and emergence, regulates water balance and absorbs solar energy to give chemical energy (Acquaah, 2007).

2.10.1 Mechanism of drought tolerance in crops

Drought resistance genotype is defined as a genotype that outperforms another under acute drought stress (Blum, 2005). Drought stress occurs in crops when soil water levels are low and crop water demand exceeds supply (Raza *et al.*, 2021). Plants can withstand drought in a variety of ways or mechanisms, including avoiding and tolerating dehydration/desiccation by reducing plant size, leaf area, and leaf area index, increasing water use efficiency, adjusting osmotic pressure, and capturing water from moisture through their rooting system, among others (Blum, 2005). Physiological measurements are used to assess the drought resistance of a crop, as well as to determine the duration and severity of the stress (Hassan *et al.,* 2020). Drought stress can reduce store root output at any stage of growth during the growing season. The early development stage, storage root initiation, and developmental phases of sweet potato, on the other hand, are the most fragile and sensitive.

A decline in yield is described as a decrease in the number of tubers produced as well as a decrease in the size of the tubers produced. Drought also has an impact on tuber quality because it causes elongated or very thin tubers as a result of variable maturation and re-growth of the top, tuber cyclic cell expansion, and cracks. Drought tolerance is defined as a genotype's relative yield in comparison to other genotypes under the same drought stress (Hall, 2010). Stress is a topic of concern for scientists due to the large range of factors influencing crop drought response (Hall, 2010). A genotype is drought resistant when it produces an economically viable crop within the restrictions of its production capabilities when water is scarce (Ekanayake, 2009; Ceccarelli & Grando, 2011). Drought resistance and its components are being redefined all the time (Ekanayake, 2009). Drought resistance can be handed down to a genotype via drought escape, tolerance, avoidance, and recovery routes (Blum, 2005). These strategies are not mutually exclusive and allow the crop to withstand drought at any stage of development. Due to escape mechanisms, drought-sensitive growth phases can be completed during periods of adequate precipitation, or the cycle can be completed before a drought develops (Ceccarelli & Grando, 2011).

Avoidance refers to a plant's ability to survive or escape stress by maintaining high water potentials via higher levels of water absorption due to a more widely distributed and larger root system, as well as avoiding water loss via stomata control. The ability to bear internal stress generated by dehydration tolerance or avoidance tactics is referred to as tolerance (Ceccarelli & Grando, 2011).

2.11 Drought evaluation and screening methods

Stress tolerance is defined as the difference in yield between stress and non-stress situations, whereas mean productivity is the average output in both stress and non-stress. Equations for the genetic correlations of tolerance and mean productivity with one another and with yields in stress and non-stress settings are developed using the ratio of genetic variances and the genetic correlations between yields in stress and non-stress situations (Tumuhimbise *et al.*, 2014). These equations show that selecting for stress tolerance generally results in decreased mean yield and productivity in non-stress settings. Selecting for mean productivity will frequently enhance mean yields in both stress and non-stress scenarios.

Tolerance and mean production exhibit negative genetic association when the genetic variance in stress situations is less than the genetic variance in non-stress contexts. This finding explains why there are frequently positive correlations between regression coefficient stability and mean productivity: a line with high-stress tolerance might well have low regression coefficient stability, and genetic variances in stress environments are generally lower than in non-stress environments (Tuberosa *et al.*, 2002).

2.11.1 Drought tolerance indices

Several drought indices exists, which includes, stress susceptibility index (SSI) (Fischer & Maurer, 1978), stress tolerance index (STI) (Fernandez, 1992), geometric mean productivity (GMP), and tolerances (TOL) and mean productivity index (MP) (Roselle & Hamblin 1981). The SSI classifies genotypes as neutral if their SSI value is one, sensitive if it is greater than one and tolerant if it is less than one. After applying the algorithm, low SSI scores imply that the genotype is tolerated (Bruckner & Froherg, 1987).

Fernadez (1992) developed a stress tolerance index (STI), which is determined using Fernadez's geometric mean productivity (GMP) formula (1992). Higher STI values are connected with greater stress tolerance and yield under stress. A higher TOL score suggests greater stress tolerance, which is ideal when combined with high mean productivity levels (Rosielle & Hamblin, 1981). The STI and GMP indices were discovered to be a more valid criterion for choosing heat tolerance and high producing genotypes by Khodarahmpour *et al* (2011). The MP index was discovered by Eivazy *et al.* (2013) to be the best criterion for selecting genotypes with high grain production in both well-watered and drought-stressed environments. According to Ganjali *et al.,* (2009), MP, GMP, and STI had positive and extremely significant associations with yield in both stressed and non-stressed circumstances. Jabbari *et al.* (2018) looked at drought tolerance indices in sunflower genotypes and found a significant and positive association between STI and grain yield under non-stressed, mild, and severe drought stress conditions. According to Daneshian & Jonoubi (2008), the most useful indices for assessing sunflower resistance to drought stress are MP, GMP, and STI.

In certain studies, YI was used to rank genotypes based on yield under stress circumstances (Sio-Se Mardeh *et al.,* 2006). Drikvand *et al.* (2012) discovered that the best genotype identification criteria in irrigated and rain-fed situations were GMP, MP, STI, and HARM. Anwar *et al.* (2011) discovered strong positive relationships between grain yield and HARM, GMP, MP, and STI under irrigated and stressed conditions. Fernandez (1992) classified genotypes into four groups based on how well they perform in stressful and non-stressed conditions.

CHAPTER THREE: MATERIALS AND METHODS

3.1 To morphological characterization of sweet potato genotypes and select those with the potential dual-purpose traits

3.1.1The research study area

The research was conducted in the Boloso sore district, which is one of the 16 districts located in the Wolaita Zone. This area is situated approximately 420 kilometers to the south of Addis Ababa in the Southern Nations, Nationalities, and Peoples Region (SNNPR) of Ethiopia (Figure 3.1). The Wolaita Zone is one of the most densely populated zones in the Southern Nations, Nationalities, and Peoples Region (SNNPR), and the Boloso sore district has a total population of 207,657 individuals residing on a land area of 4537.5 square kilometers. This area is located between latitudes 6°4N to 7°1N and longitudes 37°4E to 38°2E, and comprises three agro ecological zones, namely, midland (Weyna dega), lowland (Kola), and highland (Dega), as reported by Gecho *et al.* (2014). The region is mostly characterized by highlands, covering a significant portion of the midland, with some lowland areas situated along the edges. The altitude ranges from 501 meters above sea level in the Damota highlands to 3000 meters above sea level in the Bilate Tena lowlands. The amount, duration, and frequency of rainfall differ considerably across the different agro ecological zones (AEZs).

Bilate Tena receives an average annual rainfall of 800 millimeters, while Wolaita Sodo receives an average of 1,200 millimeters. The maximum and minimum temperatures in the region range between 15 and 30 degrees Celsius, respectively, on an annual basis.

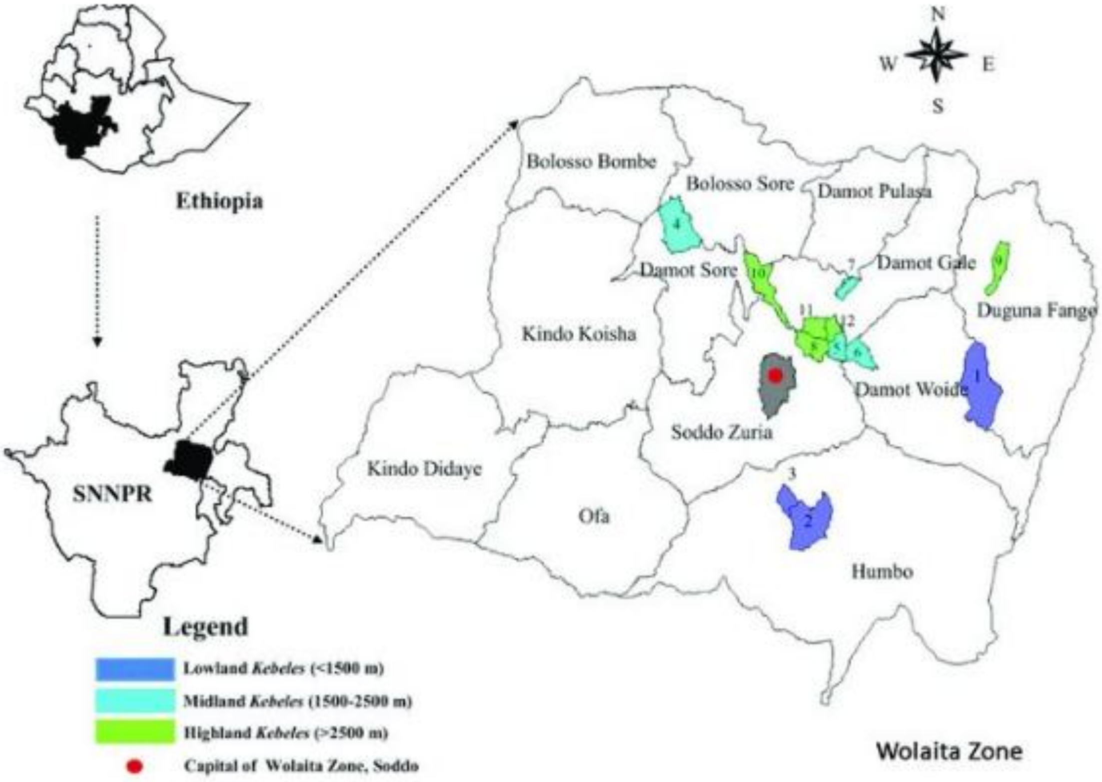

Figure 3.1 Administrative map of wolaita zone (Labisso, 2020)

The region experiences a highland and lowland geography, with rainfall ranging from an annual average of 1300mm in the highlands to 600mm or less in the lowlands. Rainfall occurs in two seasons, with the most significant rainfall happening between June and September and the least between February and March, which is referred to as belg. Belg rains are unpredictable and inconsistent, and if one or both rains fail, the region experiences scarcity. The lowlands of the region have been particularly affected by drought, as have other eastern parts of Ethiopia.

Although farm fields' in Wolaita, Ethiopia are relatively small, agriculture remains the primary source of income for farmers. In fact, more than half of the homes in the area are located on less than 0.25 hectares of land, and many people are landless due to high population density and limited land availability (WZFEDD, 2012). However, land is a valuable resource for economic and social reasons, as the region's soils are primarily sesquioxides and moderately to extremely acidic nitosols, and soil erosion has been severe due to deforestation (Mesfin, 1998). Despite these challenges, a variety of crops are grown in the area, including tef (*Eragrostis* tef (Zucc.) Trotter), maize (*Zea mays* L.), bread wheat (*Triticum aestivum* L.), haricot bean (*Phaseolus vulgaris* L.), field pea (*Pisum sativum* L.), potato (*Solanum tuberosum*), sweet potato (*Ipomea batatas* (L) Lam) (*Coffea arabica*), while eucalyptus trees (*Camaldulensis spp*.) are dominant in the landscape. Other plant species including Croton (*Croton macrostachyus* Hochst. ExRich.), Cordia (*Cordiaafricana* Lam.), Erythrina spp., podocarpus (*Podocarpus falcatus*), and Juniperus spp. (*Juniperus procera*) can also be found in the area (Tuberosa *et al.*, 2002).

3.1.2 Planting Materials

The study utilized 40 sweet potato genotypes that were selected from the International Potato Center (CIP) in Kenya and germplasm advanced from a crossing experiment carried out by the Hawassa Agricultural Research Center (Fekadu *et al.*, 2018) in Ethiopia. The goal was to conduct a phenotype characterization of these genotypes Table 3.1. Ten Orange fleshed sweet potato (OFSP) genotypes were chosen and planted to assess drought tolerance and other moisture stress tolerance selection indices, with the best ones being used to identify drought-tolerant sweet potato types.

Table 3.1 Selected sweet potato genotypes from CIP that were used in morphological characterization

Genotype code	Origin/Skin color	Flesh color
(Wogabolige)/T34	purple red	Creamy
(New Kawogo)/T33	pink	Cream
(Carrot C) /T32	white	Cream
(Jane)/T18	white	Creamy
(MUSG014019-7-22)/T16	cream	Deep orange
(CN1448-4926-6)/T3	pink	Deep orange
(MUSG014052-51-25) /T9	pink	Deep orange
(MUSG014052-51-11)/T15	pink	Deep orange
(CN1448-49-28-8)/T31	pink	Deep orange
(CN1448-49-26-7)/T28	cream	Deep orange
(MUSG11033-6-1) /T1	cream	deep orange
(MUSG014065-21-13)/T21	cream	deep orange
(MUSG014052-51-23)/T14	cream	deep orange
(MUSG014065-21-14)/T27	cream	deep orange
(MUSG014019-7-50) /T25	cream	deep orange
(MUSG014001-3-12) /T13	cream	very deep orange
(CN1448-49-28-9)/T20	cream	very deep orange
(MUSG014001-3-11)/T5	pink	very deep orange
(CN1448-49-28-17)/T19	cream	Intermediate orange
(MUSG014052-51-35)/T10	cream	Intermediate orange
(Naspot-12)/T39	pink	Intermediate orange
(MUSG014046-20-2) /T2	pink	Intermediate orange
(MUSG014052-51-19)/T26	cream	Intermediate orange
(Ukr/Eju-10)/T35	white	Intermediate orange
(Naspot-13) /T40	white	Intermediate orange
(Ukr/Eju-13)/T36	white	Intermediate orange
(Tio Joe-2) /T24	pink	Intermediate orange
(MUSG014019-7-50)/T11	white	Intermediate orange
(MUSG014001-3-41)/T8	cream	Intermediate orange
(Kabode)/T37	pink	Intermediate orange
(Vita)/T38	pink	Intermediate orange
(MUSG014019-7-43)/T17	pink	Intermediate orange
(MUSG014012-2317-6)/T22	cream	Intermediate orange
(MUSG014001-3-42) /T7	pink	Intermediate orange
(MUSG014012-26-13)/T4	pink	pale yellow orange
(MUSG014001-3-11) /T12	pink	pale yellow orange
(M2USG014012-26-32) /T23	cream	pale yellow orange
(MGSG1006-7-4)/T30	white	pale yellow
(MUSG014001-3-49)/T29	cream	pale orange
(MUSG014001-3-59)/T6	pink	pale orange

3.1.3 Field culture, planting and harvesting

To prepare the field for planting, it was first cleared, then ploughed and harrowed. The study was conducted using an alpha lattice design, with three replications and a total of 15 vine cuttings were planted at a depth of 4-6 cm. To ensure proper planting, half of the vine cuttings were planted at an angle with the vine ends facing towards the center of the ridge. Initially, a basal dose of NPK fertilizer in the ratio of 20:40:60 per hectare was applied in two separate doses. The first dose was given at the time of planting, and the second was given approximately after a month and week. The first weeding occurred two weeks after planting, while the second weeding was done two weeks later while the earthling-up process was being conducted.

3.1.4 Research design and Data collection

The experiment for the first objective took place on a field in the Wolaita zone of the Boloso sore district between August and December 2019. This experiment was conducted in the field using an alpha lattice design with two replications. Genotypes were planted in three rows per plot, with four plants per row, with a row spacing of 60 cm and a plant spacing of 30 cm, respectively. Each plot was made up of three 1.80m long ridges, each with four plants. The distance between the ridges was 60cm, resulting in a gross plot area of 2.6m^2. Planting material was vine tip cuttings, which were planted at a depth of 4-6 cm.

3.1.5 Evaluation of morphological variables

Morphological characterization of the 40 sweet potato genotypes was performed at 90 and 180 days after planting (DAP) using a total of 15morphological descriptors such as vine, leaf, and storage root descriptors. This was accomplished by the application of international sweet potato descriptors developed by CIP, AVRDC, and IBPGR (Huaman, 1991) (Table 3.2). Field observational yield trials were conducted in order to evaluate the performance of different genotypes. These trials used the descriptors provided by the International Potato Center (CIP) to assess the characteristics of each genotype. The purpose of these trials was to identify genotypes that did not meet the minimum acceptable value for the descriptors.

Table 3.2 List of CIP descriptors used for characterization of sweet potato genotypes

Morphology	Acceptable description	CIP score
Twining/ The vines' ability to climb adjacent stakes	Moderately twining	5
Plant Type/ **Growth Habit** (length of the main vines) at around 90 DAP	Spreading(151 cm – 250cm)	7
Ground Cover/ Estimated ground cover percentage recorded.	High (75%-90%)	7
Vine Internode/ The vine internode or 3 internodes measured at the central region of the vine.	Intermediate length(6 cm – 9cm) Thick Diameter(10 mm – 12mm)	5
Vine color/ Pigmentation pigmentation of the vine	Green	1
Vine Apex/ tip pubescence Hairiness at the tip of immature leaves	Sparse	3
Mature leaf shape/ The leaves in the middle region of the shoot have a mature leaf form.	1. Rounded, 2.Reniform, 3. Cordate, and either 4. Triangular	1,2,3 and 4
Leaf lobe shapes/	No side lobes /Very slender teeth	0,1
Mature leaf size/ The length of three leaves in the vine's core region measured from the base to the tip.	Large(16 cm – 25cm)	7
Vein leaf pigmentation/ the color of the vein leaf pigmentation/	Green	2
Storage root	1 Tuberous root shape; Round elliptic, Elliptic, Long-Elliptic	2,3,8

	2 Storage root cortex thickness - Intermediate(3mm)	5
	(iii)Tuberous root peel color Any	1-9
	(iv)Storage root flesh color Any	1-9

3.1.6 Evaluation of Root-Vine ratios (RVs)

The root to vine $({}^{\boldsymbol{R}}/_{\boldsymbol{V}})$ $\boldsymbol{R}$atio was used to classify dual-purpose use cultivars, according to Leon- Velarde et al., (2001).

The ${}^{\boldsymbol{R}}/_{\boldsymbol{V}}$ ratio is calculated using the formula$\frac{\boldsymbol{R}}{(\boldsymbol{R}+\boldsymbol{V})}$

- According to Leon-(2001) Velarde's dual-purpose classification,

1. Forage (F), ${}^{\boldsymbol{R}}/_{\boldsymbol{V}}$ 0.2

2. DP (F), R/V ranges between 0.2 and 0.3 for dual-purpose high forage.

3. R/V ranges between 0.3 and 0.55 for dual purpose high root, DP (R).

4. R/V ranges >0.55 for root (R).

To estimate the root: vine (R/V) ratios, the ratios of vine to tubers of each cultivar were computed based on the ratio of store roots over biomass$\frac{\boldsymbol{R}}{(\boldsymbol{R}+\boldsymbol{V})}$. Cultivars were classified as forage (F), RV 0.2; dual-purpose high forage, DP (F), RV 0.2> RV 0.3; dual-purpose high root, DP (R), RV 0.55, and root (R) RV> 0.55 by Leon-Velarde (2001).

Varieties of sweet potato that are intended for dual-purpose and forage production generally produce a greater amount of vines compared to storage roots, whereas dual-purpose varieties that prioritize root production tend to generate more storage roots than vines.

3.2 To evaluate the response of orange flesh sweet potato genotypes to different drought stress conditions, and identify genotype with good yield

3.2.1 Seedling material

From February to July 2020, a second experiment was conducted in the field to evaluate and screen ten selected orange fleshed sweet potato (OFSP) genotypes for drought tolerance those are selected from 40 genotypes from the first experiment. These genotypes included (Naspot-12), (MUSG014001-3-11), (CN1448-49-28-8), (MUSG014052-51-35), (MUSG014019-7-22), (Vita), (MUSG014065-21-13), (MUSG014065-21-14), (MUSG014019-7-50) and (Wogabolige).

3.2.2 Research design

Drought screening was carried out using Alpha lattice design with three replications in the field. Genotypes were planted in three rows in each plot, with five plants per row, with 30 cm between plants and 60 cm between rows. Length: 30 cm planting material was vine tip cuttings, which were planted at a depth of 4-6 cm. The tuber yields and other morphological parameters of the 10 orange-fleshed sweet potato varieties were evaluated in field experiments under three different water regimes. The first condition was fully irrigated, denoted as T0, where plots were irrigated until harvest. The second condition was medium water-stressed, denoted as T1, where plots were watered for a month and 11 days and then water stress was imposed. The third condition was extreme water-stressed, denoted as T2, where plots were watered for a month and 11 days, water stress was imposed for a month and 6 days, and then water stress was again imposed until harvest. To identify drought-resistant sweet potato genotypes and understand their physiology and yield under different water stress conditions, field experiments were conducted. In order to ensure proper establishment of sweet potato plants, all plots were consistently irrigated during the night for approximately a month and 11 days, from January 1st to February 11th, 2020. Starting on February 12th, 2020, water stress was induced by not watering the plots of T1 and T2, while the control (T0) was regularly irrigated in the evenings until harvest. T1 was subjected to moderate drought stress, while T2 experienced severe moisture shortage, with no water applied until harvest. Moisture stress was imposed on T1 and T2 for almost a month and six days, from February 12th to March 18th, 2020. Starting from the evening of March 18th, only the T1 plots experiencing moderate drought stress were given water. From this point until the harvest on June 30th, 2020, only the T0 (control) and T1 plots were watered. Meanwhile, the T2 plots continued to experience water stress until harvest, starting from the first water stress-imposed time.

3.2.3 Morphological parameters

Table 3.3 List of morphological parameters collected and recorded

Morphological characters	Description
Vine length at 90 DAP (VL)	A measuring tape was used to determine the length of two of the most robust vines. It was measured from the point of soil contact to the apical tip, and to acquire an exact reading, the vines were straightened.
Vine Inter-node length (VIL)	This was determined by recording and calculating the distance between the vines' nodes and the length of vine internodes was measured in centimeters three months after sowing by taking a representative portion or the center portion of vines from five sampled plots.
Vine Inter-node diameter (VID)	A tool called Calipers was used to measure three internodes in the center region of the vine.
Number of branch (NB)	Five samples were chosen to count and record their branch number, which was obtained by counting the number of branches per plant.
Vine Fresh weight (VFW)	The total above biological biomass yield in kg from each plot during harvest was used to calculate the fresh weight of the vines per plot.
Root yield (RY)	This is the sum of the storage roots' weight. The total root yield from the sampled plants to the entire plots was measured in tons per hectare, and the average was reported.
Leaf area (LA)	The area of the leaf was measured and calculated by dividing the length by the width. Leaf area (cm2) = Leaf length (cm) x Leaf breadth (cm) (cm). By randomly picking 5 leaves from each plot, the area of the leaves in the middle of the plant was measured.

3.3 To asses various drought stress tolerance selection indices and select the best ones for their applicability to identify drought tolerant sweet potato varieties

The experiment was conducted in a field in Boloso sore district Wolaita Zone, Ethiopia. Alpha lattice design with three replications for each stress and non-stress condition was used and genotypes were planted in three rows each plot, with five plants per row, with the spacing of 30 cm between plants and 90 cm between rows. The planting material was 30cm vine tip cuttings, which were planted at optimum depth of 4-6 cm. planting sweet potato cuttings at a depth of 4-6 cm is recommended because this depth provides the right balance of moisture, temperature, and oxygen for the cutting to take root and establish a healthy plant. If the cutting is planted too shallow, it may not get enough moisture and may dry out quickly. On the other hand, if the cutting is planted too deep, it may not get enough oxygen, which can lead to root rot and poor plant growth. Therefore, a depth of 4-6 cm is considered optimal for sweet potato planting. However, the specific depth may vary based on factors such as soil type, climate, and other growing conditions. The storage root yield data for each genotype were recorded in both non-stress and stress environments and they were used to generate and analyze several drought selection indexes using the following formulas in MS Excel (Table 3.3).

Table 3.4 List of drought tolerance indices and their formula's

	Drought indices	Formula's
1	Stress susceptibility index (SSI) (Fischer &Maurer, 1978)	$SSI = (1- (Ys/Yp)/SII$
2	Geometric mean (GM): (Fernandez, 1992)	$GM = (Yp*Ys)^{1/2}$
3	Tolerance (TOL): (Rosielle & Hambline, 1981)	$TOL = (Yp-Ys)$
4	Mean productivity index (MPI) (Rosielle & Hambline, 1981)	$MPI = (Ys+Yp)/2$
5	Yield stability index(YSI): (Bouslama & Schapaugh, 1984	$YSI=Y_S/Y_P$
6	Harmonic mean productivity(HM): (Kristin *et al.*, 1997)	$HM= ½((1/Y_s) + (1/Y_p)$
7	Stress tolerance index (STI): (Fernandez, 1992)	$STI = (Ys xYp)/Yp$
8	Yield index (Gavuzzi P *et al.*, 1997)	$YI = (Ys/ \bar{Y}s)$
9	Stress intensity index (SII) : (Fischure & Maurer, 1978)	$SII = 1- \bar{Y}s/\bar{Y}p$

Ys, Yp, s, and p in the above formulas denote yield under stress, yield under non-stress for each genotype, and yield mean in stress and non-stress circumstances for all genotypes, respectively.

3.3.1 Ranking of sweet potato genotypes

For drought indicators, mean data is utilized to calculate rank sum (RS), rank sum of standard deviation (RSD), and correlation. A rank- sum (RS) was computed using the following relationship formula for screening drought-tolerant genotypes:

Rank sum (RS) = Rank mean (R) + Standard deviation of rank (SDR) (Farshadfar *et al.*, 2011)

$SDR= (S^2i)^{0.5}$

3.4 Statistical analysis

Analysis of variance (ANOVA) was performed on the data produced in this study using R software, Agricolae package, partially balanced incomplete block (PBIB), test function. The mean values were used to calculate simple correlation coefficients between traits. The tukey test was used to compare significantly different means at the $\alpha \leq 0.05$ and $\alpha \leq 0.01$level.Correlation analysis was performed between drought selection indices and yield under stress and non-stress environments.

3.4.1 Principal component analysis and cluster analysis

The first component generated in a principal component analysis accounted for the maximum amount of total variance in the observed variables, and it was used to highlight some similar traits as the most essential for identifying the variation within and across the sweet potato genotypes. Dendrograms were created using cluster analyses of morphological features to look at the phenotypic relatedness of the 40 sweet potato variants. SPSS (version 20.0) was used to conduct both cluster and principal component analyses. Based on the Euclidean distance coefficient, the Unweighted Pair Group Method of Arithmetic Averages (UPGMA) of 40 genotypes was developed utilizing 15 morphological characters.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter focuses on applying various international criteria to classify sweet potato cultivars as dual-purpose and measuring their drought endurance using various water stress extended durations.

The purpose of this study was to morphologically characterize sweet potato genotype in Ethiopia and categorize them in order to select those with optimal dual-purpose characteristics that could be used as a suitable parent for future breeding programs, to evaluate the response of orange-fleshed sweet potato (OFSP) genotypes to drought stress and identify cultivars with high yield and high quality and to assess various drought stress tolerance selection indices and choose the appropriate ones to use in identifying drought tolerant genotypes. In order to achieve the objectives forty (40)sweet potato varieties were tested for characterization study and their optimal dual-purpose performance/potential, and 10 orange-fleshed sweet potato varieties were evaluated for drought tolerance using morphological descriptors taken from the first experiment.

Fifteen (15) morphological descriptors were used to examine morphological diversity among 40 sweet potato genotypes. In order to show the significantly mean difference among the 40 genotypes, The mean score of the vegetative and root parameters, such as vine, leaf, and root characteristics, is shown in Tables 4.1, 4.2, and 4.3, respectively. For dual-purpose classification, the root-to-vine ratio (R/V) was calculated using the León-Velarde (2000) approach. The R/V ratio formula was used to split the genotypes into four categories after they were computed. PCA and Cluster analysis were performed and presented to show which traits contributed the maximum variation observed across the genotypes and to show which genotypes showed a shared traits and grouped them together. Using ten orange-fleshed sweet potato genotypes from the first trial, drought tolerance variants were screened. Drought tolerance was tested using three different water stress conditions: zero (T0), moderate (T1), and extreme (T2) and the result were presented on the table 4.1, 4.2, and 4.3 respectively. To identify the genotypes that have a high capability of tolerating drought, nine different drought indices were computed and Rank Sum (RS) formula was used for genotype ranking. Additionally, correlation analysis was performed to determine which drought index had a stronger relationship with yield under both water-stressed and non-stressed environments. The index that had the highest correlation was selected as the best index for identifying drought-tolerant genotypes.

4.2 Phenotypic variability

Using morphological features, this study demonstrated that sweet potato exhibits a high amount of phenotypic variability. The majority of morphological features were significantly varied across the varieties evaluated in this study. It has previously been noted that sweet potato genotypes have a lot of variation (Karuri *et al.,* 2010).Vine characters, leaf characters, and storage root characters were the morphological characters that were evaluated among the varieties. ANOVA was used on 14 descriptors, and practically all morphological descriptors indicated significant differences. Appendix I, summarize the combined AVOVA for morphological characters such as the leaf, vine, and store root features.

It is critical to assess morphological diversity and interactions among sweet potato varieties, not only for germplasm conservation but also for breeding objectives, particularly when selecting superior variants (Allemann *et al.*, 2004).Sweet potatoes have several physical traits, such as leaves, vines, and roots and even under identical environmental conditions; each variety's yield will vary. As a result, based on the environmental conditions, selecting appropriate sweet potato cultivars to plant is crucial (Laurie *et al.*, 2013). Sweet potato diversity is assessed primarily by morphological characterization (Mohan *et al.*, 2012; Mwanga *et al.*, 2017). Many researchers throughout the world have employed a modified version of the sweet potato descriptors (Huamán, 1991) to define sweet potato.

4.2.1 Sweet potato vine characteristics

In tables 4.1, the means of vine-related traits on a fresh weight basis, as well as their significant differences for each trait across 40 genotypes, are provided. Almost all vine characters, such as Vine growth rate (VGR), Vine internode length (VIL), Vine internode diameter (VID), Plant type (PT), Vine pigmentation (VIP), Vine tip pubescence (VTP), and significant difference for the trait Twining (TW) and Estimated growth rate, have highly significant differences ($\alpha \leq 0.05$) (EGR). According to the research findings, there was a highly significant difference in almost all vine traits, lending support to the hypothesis. The results, as shown in Table 4.1, reveal that the vine traits of sweet potato cultivars varied greatly. This could be due to a number of reasons, including the cultivar's origin, the source of propagation material, the environment, and soil conditions.

Table 4.1 The mean score of sweet potato vine parameters under field conditions

Vine characteristics									
Variety	**VIL (score: 1-9)**	**VID (score: 1-9)**	**PL (score: 3-9)**	**VIP (score: 1-9)**	**EGC (score: 3-9)**	**TW (score: 0-9)**	**VGR**	**VTP (score: 0-9)**	**VBY**
(CN1448-49-26-7)	8.0 a	7.0defg	144.9abcde	3.0de	9.0a	7.0a	136.0abcde	0.0b	4.75
(Wogabolige)	7.3ab	10.1abcdef	151.4abcd	1.0f	8.0a	6.0a	128.5abcdefg	0.0b	14.95
(MUSG014065-21-13)	7.2ab	10.6abc	155.4ab	1.0f	7.0a	1.5a	142.6abcd	0.0b	7.35
(Naspot-12)	7.0abc	10.5abc	159.1a	5.0bc	7.0a	4.0a	154.9a	3.0a	10.05
(Vita)	7.0abc	10.2abcde	158.0a	1.0f	8.0a	4.0a	148.0ab	0.0b	8.05
(MUSG014012-26-13)	6.8abc	10.7abc	152.6abc	1.0f	7.0a	5.0a	142.6abcd	0.0b	6.9
(MUSG014065-21-14)	6.8abc	10.3abcd	156.3ab	1.0f	7.0a	4.0a	146.9abc	0.0b	7.5
(CN1448-49-28-8)	6.5abc	10.7abc	157.6a	1.0f	8.0a	0.0a	134.9abcdef	0.0b	7.6
(MUSG014019-7-50)	6.5abc	10.2abcde	30.3h	1.0f	7.0a	7.0a	140.1abcd	0.0b	6.05
(MUSG014019-7-22)	6.3abc	10.8ab	152.6abc	6.0ab	7.0a	4.0a	135.1abcdef	0.0b	12.6
(Ukr/Eju-10)	6.0abc	11.7a	152.1abc	1.0f	8.0a	6.0a	141.6abcd	0.0b	13.4
(MUSG014052-51-35)	5.8abc	7.4 bcdefg	89.4abcdefgh	1.0f	6.0a	4.0a	81.7abcdefghi	0.0b	10.35
(MUSG014001-3-11)	5.2abc	8.0bcdefg	84.8cdefgh	1.0f	7.0a	4.0a	72.6cdefghi	3.0a	12.15
(Tio Joe-2)	5.2abc	6.9defg	64.6fgh	1.0f	5.0a	3.0a	59.5ghi	0.0b	6.35
(MUSG014052-51-25)	5.0abc	6.0g	101.3abcdefg	1.0f	7.0a	4.0a	91.5abcdefghi	0.0b	3.55
(Ukr/Eju-13)	4.8abc	6.70efg	87.1bcdefgh	1.0f	8.0a	4.0a	77.6bcdefghi	0.0b	7.05
(MUSG014001-3-49)	4.3abc	5.7 g	82.1defgh	1.0f	6.0a	3.5a	73.4bcdefghi	0.0b	8.45
(New Kawogo)	4.2abc	7.5bcdefg	107.2abcdef	5.0bc	6.0a	4.0a	96.8abcdefgh	3.0a	1.596
(MUSG014052-51-11)	4.1abc	6.9defg	44.0fgh	7.0a	3.0a	0.0a	38.7hi	0.0b	2.55
(MUSG014052-51-23)	4.1abc	6.0g	72.5fgh	2.0ef	4.0a	2.5a	64.5efghi	0.0b	9.3
(CN1448-4926-6)	4.0abc	7.5bcdefg	44.0fgh	1.0f	7.0a	1.5a	34.5hi	0.0b	4.25
(MUSG014046-20-2)	4.0abc	6.5 g	76.6efgh	5.0bc	7.0a	3.0a	68.1defghi	0.0b	12.35
(Carrot C)	3.8abc	7.2cdefg	54.1fgh	1.0f	9.0a	3.0a	44.0hi	0.0b	6.55
(MUSG1006-7-4)	3.8abc	6.4g	56.9fgh	3.0de	5.0a	0.0a	47.5hi	0.0b	7.75
(CN1448-49-28-9)	3.7abc	6.0g	49.8fgh	3.0de	4.0a	1.5a	42.2hi	0.0b	8.4
(MUSG014001-3-41)	3.5abc	7.0defg	58.7fgh	4.0cd	9.0a	4.0a	49.7hi	0.0b	5.6
(MUSG014001-3-42)	3.5abc	6.2g	70.1fgh	3.0de	5.0a	3.0a	61.1fghi	0.0b	7
(MUSG014001-3-59)	3.5abc	5.0g	64.3fgh	4.0cd	6.0a	1.5a	59.2ghi	0.0b	11.7
(MUSG014012-2317-6)	3.5abc	7.0defg	66.8fgh	1.0f	3.0a	1.5a	57.7ghi	0.0b	11.45

(CN1448-49-28-17)	3.5abc	6.5 g	53.4fgh	1.0f	6.0a	1.5a	47.5hi	0.0b	5.5
(MUSG014052-51-19)	3.3abc	5.7 g	36.0gh	1.0f	5.0a	1.5a	27.1hi	3.0a	5.3
(MUSG014019-7-43)	3.2bc	5.5 g	25.4h	1.0f	5.0a	0.0a	17.2i	0.0b	7.4
(M2USG014012-26-32)	3.2bc	6.9defg	50.1fgh	7.0a	5.0a	3.0a	41.1hi	0.0b	7.1
(MUSG014001-3-11)	3.2bc	6.0g	49.1fgh	7.0a	7.0a	1.5a	46.0hi	0.0b	9.45
(MUSG014001-3-12)	3.1 bc	6.3g	27.6h	1.0f	3.0a	0.0a	19.9i	0.0b	6.05
(Kabode)	3.1 bc	8.2abcdefg	51.7fgh	1.0f	7.0a	4.0a	45.1hi	0.0b	4.9
(Naspot-13)	3.0 bc	6.70efg	32.9gh	1.0f	8.0a	2.5a	43.0hi	0.0b	9.1
(Jane)	2.9 bc	5.2g	153.5abc	1.0f	4.0a	0.0a	25.4hi	0.0b	11.55
(MUSG014019-7-50)	2.8 bc	6.0g	43.4fgh	1.0f	8.0a	2.5a	21.8i	0.0b	9.8
(MUSG11033-6-1)	2.3 c	7.0defg	43.4fgh	7.0a	7.0a	0.0a	40.4hi	0.0b	4.3

VID: Vine internode diameter; EGC: Estimated ground covers VIP: vine pigmentation VTP: Vine tip pubescence

PL: Plant Length; VIL: Vine internodes length TW: Twining ability VGR: Vine growth rate VBY: Vine biomass yield

Mean values followed by the same letters in the column are not statistically significantly different (Tukey's test ($\alpha \leq 0.05$).

Twining (TW) was lowest in CN1448-49-28-8 (0.0), MUSG014052-51-11(0.0), MUSG014019-7-43(0.0), MGSG1006-7-4(0.0), Jane, MUSG0140013 (0.0), and MUSG014001-3-12 (0.0) and highest in CN1448-49-26-7(7.0) among 40 varieties, respectively. The length of the vine internodes (VIL) varied from 2.3 mm (N1448-49-26-7) (MUSG11033-6-1) to 8.0 mm (N1448-49-26-7). The variety (MUSG014001-3-59 mm) had the smallest (5.0 mm)whileMUSG014012-26-13 (10.7) had the largest vine internodes diameter (VID) Among the varieties, (MUSG014019-7-43) (25 mm) had the lowest and Naspot-12 (159 cm) had the highest plant type (PT). The genotypes MUSG014052-51-11(3.0), MUSG014012-2317-6(3.0), and MUSG014001-3-12 had the lowest (3.0) while the genotypes CN1448-49-26-7(9.0), Carrot C (9.0), and MUSG014001-3-41(9.0) had the highest ground cover (ESG). The genotypes of vine pigmentation (VP) ranged from 1.0 to 7.0 and, the 40 varieties had varying levels of vine tip pubescence (VTP), ranging from 0.0 to 3.0. Naspot-12 (154) had the fastest vine growth rate, whereas MUSG014001-3-11 had the lowest (17.0) (Table 4.1.1). The lowest result Vine biomass yield (VBY) coming from the variety (MUSG014001-3-11) (New Kawogo) while the top four genotypes for Vine biomass yield (VBY) were (MUSG014065-21-13), (Ukr/Eju-10), (MUSG014019-7-22), and (MUSG014001-3-11), with the parameters vine internode length (VIL), vine internode diameter (VID), plant type (PT), vine pigmentation (VIP), estimated growth covers (EGC), and vine growth rate (VGR) were likewise higher in these genotypes. Table 4.1shows that three vine characteristics variables, vine growth rate (VGR), plant type (PT), and vine internode length, showed the largest diversity in the 40 varieties. The length of the vine, or the plant type, varies between 25 and 159.1 cm. Naspot-12 was the variety with the longest vines among all, while MUSG014019-7-43 had the shortest vines and was quite short. At 90 days following planting, the variety Naspot-12 had the highest vine growth rate (VGR), whereas the variety MUSG014019-7-43 had the lowest. In comparison to other vine varieties, the study discovered that Naspot-12 had the greatest value in practically all vine traits.

The research findings indicate that sweet potato cultivars have a wide range of vine traits, and the diversity is mainly due to the cultivar's origin, the source of propagation material, the environment, and soil conditions. The study also revealed that Naspot-12 had the highest vine growth rate and greatest value in almost all vine traits compared to other varieties. Additionally, the study found that some genotypes had a low level of twining, which could be an advantage in mechanical harvesting. However, further research is needed to explore the impact of low twining on yield and tuber quality.

The results also suggest that vine biomass yield (VBY) is influenced by several factors, including vine internode length (VIL), vine internode diameter (VID), plant type (PT), vine pigmentation (VIP), estimated growth covers (EGC), and vine growth rate (VGR). The top four genotypes for VBY were identified as (MUSG014065-21-13), (Ukr/Eju-10), (MUSG014019-7-22), and (MUSG014001-3-11), with higher values for the mentioned vine traits.

In conclusion, the research findings provide valuable insights into the variability of vine traits among sweet potato cultivars, which can be used to develop breeding strategies for improving yield and quality. The identification of genotypes with desirable vine traits, such as low twining and high VBY, can contribute to the development of new cultivars that are better suited to different production environments and market demands.

Overall, these findings highlight the importance of understanding and characterizing the genetic and environmental factors that contribute to variation in sweet potato vine traits. Such knowledge could be used to inform breeding programs aimed at developing cultivars with desirable traits, such as high vine biomass yield or rapid vine growth rate.

Analysis of variance revealed that there are highly significant differences in leaf character such as mature leaf size (MLS), Leaf vine pigmentation (LVP), and Leaf lobe number among the 40 varieties leaf lobe number (LLN). The length of the central leaf lobe (CLL) and the length of the petiole (PL) were not statistically different ($\alpha \leq 0.05$) (Appendix I). A genotypesCN1448-49-28-8 had the shortest petiole length (14.2 mm) while New Kawogo had the longest petiole length (PL) of 18.5 mm, and, MUSG014019-7-43(12.6 mm) had the smallest mature leaf size whereas Wogabolige (17.3 m^2) had the largest mature leaf size. The number of leaf lobes (LLN) varied between 0.0 and 5.0. The central leaf lobe had a range of 0.5to 8.0. Leaf veins ranged from 0.0 to 5.0. (Table 4.2)

4.2.2 Sweet potato leaf characters

Table 4.2 The mean score of sweet potato leaf parameters under field conditions

Leaf characteristics					
Variety	**MLS (score: 0-9)**	**SCLL (score:0-9)**	**PTL (score:0-9)**	**LVP (score:0-9)**	**LLN (score:0-9)**
(MUSG014012-26-13)	17.6a	1.00a	18.1a	3.0c	1.0b
(Wogabolige)	17.3ab	3.0a	16.5a	2.0b	5.0a
(MUSG014019-7-22)	17.2ab	3.0a	14.5a	5.0d	5.0a
(MUSG014065-21-13)	17.1abc	6.0a	15.0a	2.0b	5.0a
(New Kawogo)	17.1abc	8.0a	18.5 a	3.0c	3.0b
(Naspot-12)	17.1abc	6.5a	17.4a	3.0c	3.0b
(Ukr/Eju-10)	16.9abcd	7.5a	14.6a	5.0d	5.0a
(Vita)	16.7abcde	7.5a	16.3a	2.0b	5.0a
(CN1448-49-28-8)	16.5abcde	6.0a	14.2a	2.0b	5.0a
(MUSG014019-7-50)	16.4abcdef	8.0a	15.3a	3.0c	1.0d
(Carrot C)	16.0abcdef	4.0a	18.3a	2.0b	5.0a
(MUSG014065-21-14)	15.4abcdef	6.0a	16.8a	5.0d	5.0a
(Naspot-13)	15.0abcdef	5.0a	17.3a	2.0b	5.0a
(CN1448-49-26-7)	14.8abcdef	3.5a	17.0a	5.0d	5.0a
(M2USG014012-26-32)	14.8abcdef	8.0a	16.1a	2.0b	3.0b
(MUSG014052-51-25)	14.8abcdef	6.0a	14.7a	2.0b	3.0b
(Tio Joe-2)	14.7abcdef	6.5a	15.40a	2.0b	3.0b
(MUSG014001-3-42)	14.5abcdef	4.0a	16.8a	2.0b	1.0d
(MUSG014019-7-50)	14.3abcdef	5.0a	16.5a	0.0a	3.0b
(MUSG014001-3-11)	14.1abcdef	4.5a	16.8a	3.0c	3.0b
(MUSG014052-51-11)	14.1abcdef	4.0a	14.8a	3.0c	3.0b
(Kabode)	14.1abcdef	4.0a	16.0a	2.0b	5.0a
(Ukr/Eju-13)	14.1abcdef	3.5a	17.1a	2.0b	5.0a
(CN1448-4926-6)	14.0abcdef	5.0a	17.3a	5.0d	5.0a
(MUSG014001-3-41)	14.0abcdef	7.5a	15.3a	5.0d	5.0a
(MUSG014001-3-49)	14.0abcdef	3.0a	15.6a	2.0b	1.0d
(MUSG014046-20-2)	14.0abcdef	4.0a	15.7a	3.0c	1.0d
(MUSG014012-2317-6)	13.9abcdef	3.0a	15.8a	2.0b	0.0d
(MUSG014052-51-23)	13.9abcdef	1.0a	15.9a	3.0c	1.0b
(CN1448-49-28-9)	13.8abcdef	8.0a	15.0a	5.0d	5.0a
(MUSG014001-3-59)	13.8abcdef	6.5a	15.1a	5.0d	5.0a
(MUSG11033-6-1)	13.8abcdef	3.5a	15.6a	3.0c	3.0b
(MGSG1006-7-4)	13.6bcdef	3.5a	14.5a	0.0a	0.0d
(MUSG014052-51-19)	13.6bcdef	6.0a	16.3a	2.0b	5.0a
(MUSG014052-51-35)	13.6bcdef	2.0a	16.5a	3.0c	3.0b
(MUSG014001-3-12)	13.5bcdef	4.0a	14.1a	3.0c	3.0b
(CN1448-49-28-17)	13.3cdef	7.5a	15.0a	2.0b	5.0a
(MUSG014001-3-11)	13.1def	2.0a	16.0a	3.0c	3.0b
(Jane)	13.0ef	7.5a	14.7a	2.0b	5.0a
(MUSG014019-7-43)	12.6f	6.0a	13.3a	2.0b	3.0b

MLS: Mature leaf size LLN: Leaf lobe number LVP: Leaf vein pigmentation SCLL: Shape of central leaf lobe PTL: Petiole length

Means value followed by the same letters in the column are not statistically significantly different (Tukey's test (α≤0.05).

The results showed that leaf characteristics such as mature leaf size (MLS), Leaf lobe number (LLN), Leaf vein pigmentation (LVP), Shape of central leaf lobe (SCLL), and petiole length varied across 40 sweet potato types (PL). In the cultivation of dual-purpose sweet potatoes (food and fodder), phenotypic aspects of the leaf outline are important (Shumbusha *et al.*, 2017). Elameen *et al.* (2011), for instance, calculated the number of leaf lobes (LLN), the shape of the central leaf lobe (SCLL), and the mature leaf size (MLS). Because it is unaffected by the environment, this trait is highly significant in the selection of dual-purpose sweet potatoes (Huaman, 1999). Sweet potato leaf outline was also reported as a prominent expression of the crop's variability (Karuri *et al.*, 2010). The different leaf shape and outline presented on the plate 4.3. The dual-purpose sweet potato provides for a limited number of toppings, allowing for a year-round supply of fodder without negatively impacting root production (Claessens *et al.*, 2008).

Plate 4.1: Leaf vein pigmentation (ii) and distinct leaf shapes and petiole lengths I of both immature and mature leave in different varieties. The immature leaf is depicted by the red arrow, whereas the mature leaf is depicted by the black arrow

4.2.3 Sweet potato root characters

Most root characters (Table 4.3) genotypes indicated a highly significant difference ($p \leq 0.01$) for root characters, storage root yield (SRYld t/ha), root peel color (RPC), root flesh color (RFC), and substantial variation for the trait root shape across the 40 varieties (RS). However, root thickness (RT) did not differ much. A variety Carrot C (17.4) had the largest storage root yield ton-ha (SRYld), while MUSG014052-51-23 had the lowest (3.2). Root shape (RS) ranged from 8.0 to 2.0, with the largest root thickness (RT) in (MUSG014019-7-50) (7.6) and the lowest in (MUSG014012-2317-6) (2.6). Root flesh colour (RFC) varied between 9.0 and 2.0 across the 40 types, whereas Root peel colour (RPC) varied between 8.0 and 1.0 (Table 4.3)

Table 4.3 The Mean score of storage root characteristics under field conditions.

	Storage root characteristics				
Variety	**SYLD^{-ha}**	**SRCT**	**RPC (score: 0-9)**	**RS (score: 0-9)**	**RFC (score: 0-9)**
(Carrot C)	17.4a	6.2a	1.0d	7.0a	2.0f
(Ukr/Eju-10)	16.3a	5.3a	1.0d	5.0a	7.0c
(CN1448-4926-6)	12.9b	5.4a	6.0b	2.0a	8.0b
(CN1448-49-28-17)	12.1bc	6.7a	2.0c	8.0a	7.0c
(M2USG014012-26-32)	11.9bcd	6.8a	2.0c	2.0a	4.0e
(Naspot-12)	11.9bcd	5.5a	6.0b	5.0a	7.0c
(New Kawogo)	11.7bcd	7.0a	6.0b	7.0a	2.0f
(MUSG014052-51-25)	10.8bcde	4.0a	6.0b	5.0a	8.0b
(MUSG014001-3-11)	10.0cdef	6.1a	6.0b	2.0a	9.0a
(Vita)	10.0cdef	5.5a	6.0b	4.0a	7.0c
(Kabode)	9.3cdef	5.3a	6.0b	9.0a	7.0c
(MUSG014052-51-19)	9.3cdef	7.1a	2.0c	9.0a	7.0c
(CN1448-49-28-8)	9.1def	5.1a	6.0b	7.0a	8.0b
(MUSG11033-6-1)	8.5ef	6.0a	2.0c	5.0a	8.0b
(Wogabolige)	8.5ef	5.0a	8.0a	5.0a	2.0f
(MUSG014001-3-42)	7.6fg	6.8a	6.0b	2.0a	7.0c
(Naspot-13)	7.6fg	5.8a	1.0d	6.0a	7.0c
(MUSG014012-26-13)	7.4fgh	5.3a	6.0b	5.0a	4.0e
(MUSG014019-7-50)	7.4fgh	7.6a	2.0c	8.0a	8.0b
(MUSG014052-51-35)	7.4fgh	6.0a	2.0c	5.0a	7.0c
(CN1448-49-26-7)	5.5ghi	5.0a	2.0c	7.0a	8.0b
(MUSG014001-3-11)	5.3ghi	5.7a	6.0b	5.0a	4.0e
(MUSG014001-3-12)	5.3ghi	5.3a	2.0c	5.0a	9.0a
(MUSG014001-3-41)	5.3ghi	4.5a	2.0c	6.0a	7.0c
(MUSG014019-7-22)	5.3ghi	7.6a	2.0c	5.0a	8.0b
(MUSG014019-7-43)	5.3ghi	4.6a	6.0b	7.0a	7.0c
(MUSG014019-7-50)	5.3ghi	4.4a	1.0d	5.0a	7.0c
(CN1448-49-28-9)	5.1ghi	4.6a	2.0c	5.0a	9.0a
(MUSG014001-3-59)	5.1ghi	5.6a	6.0b	7.0a	6.0d
(MUSG014052-51-11)	5.1ghi	5.5a	6.0b	2.0a	8.0b
(MUSG014065-21-13)	5.1ghi	5.6a	2.0c	2.0a	8.0b
(MUSG014065-21-14)	5.1ghi	5.4a	2.0c	2.0a	8.0b
(Ukr/Eju-13)	5.1ghi	6.1a	1.0d	8.0a	7.0c
(MUSG014012-2317-6)	4.9ghi	2.6a	2.0c	7.0a	7.0c
(Tio Joe-2)	4.7hi	4.7a	6.0b	5.0a	7.0c
(MUSG014046-20-2)	4.2 i	4.0a	6.0b	5.0a	7.0c
(Jane)	3.6i	5.2a	1.0d	5.0a	2.0f
(MGSG1006-7-4)	3.2i	4.0a	1.0d	6.0a	4.0e
(MUSG014001-3-49)	3.2i	3.0a	2.0c	7.0a	6.0d
(MUSG014052-51-23)	3.2i	3.8a	2.0c	5.0a	8.0b

SYLD: Storage Yield per ton^{-ha}; RFC: Root flesh color RS: Root shape RPC: Root peel color

SRCT: Storage Root cortex thickness

Means value followed by the same letters in the column are not statistically significantly different (Tukey's test, $\alpha \leq 0.05$

Storage root characteristics such as Storage Yield per ton-ha, Root flesh color, Root shape, Root peel color, and Storage Root cortex thickness were discovered to be diverse among the 40 sweet potato genotypes. Richardson (2012), Rahman *et al.* (2013), and Ellong (2014) conducted research on the diverse shapes of sweet potato roots. When tubers are marketed for industrial processing, important factors include the selection of cultivars, the size of storage roots, and the shape of the roots (Haase *et al.,* 2007). During processing, the efficiency of peeling and trimming is greatly affected by the shape of the tubers (George *et al.,* 2010). According to Ellong's (2014) research, there are various colors of sweet potato storage root skin, including white, cream, yellow, pink, red, orange, and dark purple. The skin color of sweet potatoes is determined by the presence of different pigments in the root. Moreover, the study found that the 40 sweet potato genotypes also showed differences in the flesh of the tubers. These variations in both skin color and flesh of sweet potatoes are important to consider for industrial processing and marketing purposes. Different colors and textures of sweet potatoes may have different market values and be suited to different food products. The morphological character of a plant is determined by the interaction of environmental and genetic factors (variety). The two elements will interact over the plant's life cycle, resulting in roots that are either similar or completely different in shape. If the environment has a greater influence than genetics, there may be morphological disparities among groups of one species (Hughes *et al.,* 2008). Environmental conditions include soil conditions, climate, and even water availability (Mwololo *et al.,* 2012).

Leaf shape, color, petiole, leaf blade and vine, sweet potato skin color, and sweet potato flesh color are all morphological characteristics that remain permanent and unaffected by environmental stresses. Plant length, leaf stem length, leaf size, and root yield are only a few examples of morphological characteristics that can be easily influenced by the environment (Purbasari & Sumadji, 2018). The sizes of the sweet potato roots varied greatly, as shown in Table 4.3, ranging from 2 cm to 7.0 cm. The variety "Carrot C" had the largest root size, which was significantly different from the other varieties, while several varieties including CN1448-4926-6, M2USG014012-26-32, MUSG014001-3-11, MUSG014001-3-42, MUSG014052-51-11, MUSG014065-21-13, and MUSG014065-21-14 had the smallest root size. It is interesting to note that these results are lower than those reported in a previous study by Egbe *et al.* (2012). Additionally, a study conducted in Nigeria using 11 different cultivars produced tubers with diameters ranging from 0.8 to 8.23 cm and lengths ranging from 5.83 to 21.67 cm. These results are lower than those reported in a previous study by Egbe *et al.* (2012). This means that the root sizes observed in this study were smaller than the root sizes reported in the Egbe *et al.* (2012) study. This study provides additional context for the range of sizes that can be expected in sweet potatoes, and may also help inform decisions about which varieties to select for different purposes.

This highlights the significant variability in sweet potato root size across different varieties and regions. The most significant parameters in the design of grading, handling, processing, and packaging systems are width, length, and thickness (Peleg, 1985). Different shape observed in this study presented on the plate 4.4. Knowing the length, width, volume, surface area, and mass center placement can aid in the design of sorting gear, anticipating the surface required when applying chemicals, form factor (sphericity), and yield in the peeling process (surface area) (Wright *et al.*, 1986). The proportions of specific size grades and the shape of the root are crucial when roots are marketed for industrial processing (Haase *et al.*, 2007).

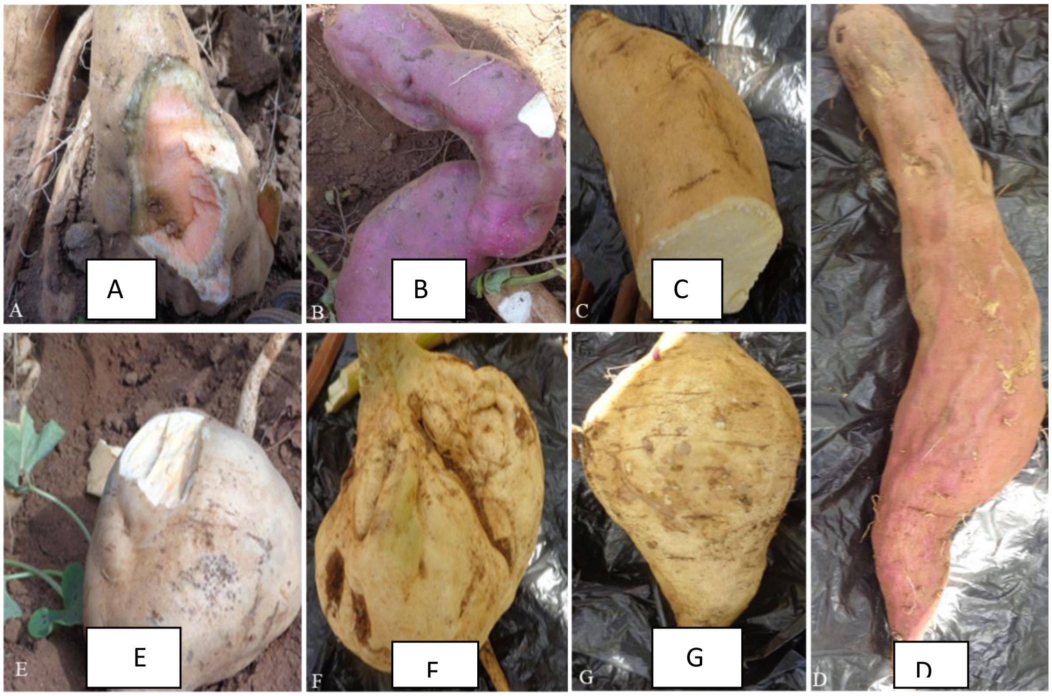

Plate 4.2: Different root shapes, skin colour and flesh colours among the genotype observed

A – Elliptic shape with thick root cortex and orange flesh color; B – Long oblong shape with purple skin and white flesh color; C – Elliptic shape with brown skin and cream flesh color; D – Long shape with light purple skin color; E –Round elliptic shape with cream flesh and skin color; F – Round shape with brown skin color. G -Long-elliptic form cream Cream colored skin.

4.3 Effect of sweet potato genotypes on tuber yield

According to the analysis of variance data, sweet potato genotypes had significant impact on storage yield (Table 4.3). Genotype Carrot C had the highest root yield, which was statistically distinct from the other genotypes, while MGSG1006-7-4, MUSG014001-3-49, and MUSG014052-51-23 had the lowest root yield. At the phenotypic level, root size and shape showed a strong positive direct effect on root yield per plant showing that they are the primary contributors to root production. From the table Table 4.1.5, we can see that some variables have a positive correlation with storage root yield, such as MLS (0.364**), EGC (0.297**), LLN (0.261**), and TW (0.126). This suggests that genotypes that have higher values for these variables may produce higher storage root yields. On the other hand, some variables have a negative correlation with storage root yield, such as LVP (-0.181) and RFC (-0.184). This suggests that genotypes that have lower values for these variables may produce higher storage root yields.

These criteria can be used to select high-yielding genotypes based on their phenotypic data. On-field morphological traits may be utilized to forecast high-producing cultivars, according to the researchers (Reddy *et al.,* 2018). Identification based on morphological character evaluation was employed to determine the diversity of varieties (Afuape *et al.,* 2011).

To ensure the proper use and preservation of sweet potato genetic resources, it is essential to study its morphological characteristics in a specific eco-geographic region. By identifying variations based on morphological parameters and distinguishing different types of sweet potatoes, germplasm production and management can be improved (Huaman 1999). This will ultimately lead to increased sweet potato productivity. However, the current identification of sweet potato types is still limited, which is one of the factors contributing to the low productivity of sweet potatoes. Therefore, further research and development in the area of sweet potato morphology is necessary to improve the management and utilization of this important crop.

4.4 Dual-purpose sweet potato varieties

4.4.1 Sweet potato root to vine ratios

The effective strategy for selecting dual-purpose sweet potato genotypes is based on the root/vine ratio, targeting those varieties that maximize vine yield while preserving good storage root productivity (León-Velarde, 2000).

The formula $\frac{R}{(R+V)}$ was used to calculate the root to vine ratios for each genotype. The outcomes for (R/V) ratios are shown in Table 4.4.Leon-Velarde (2000) classed the varieties as forage (F), RV 0.2 > RV 0.3; dual-purpose high forage, DP (F), RV 0.2 > RV 0.3; dual-purpose high root, DP (R), RV 0.3 > RV 0.55, and root (R) RV 0.55. Based on this classification approach this study found out the following genotypes qualified for dual-purpose; Wogabolige (DP(R), MUSG014019-7-22 (DP (F), Jane(DP (F), MUSG014052-51-35 DP (R), CN1448-49-28-9 DP (R), MUSG014001-3-59 DP (R), Ukr/Eju-10 DP (R), MUSG014001-3-11 DP (R), Naspot-13 DP (R), Ukr/Eju-13 DP (R) and see table 4.4 to find the rest of genotypes qualified as a dual-purpose.

Dual-purpose high forage genotypes produce more vines than storage root, whereas dual-purpose high root genotypes produce more vines than storage root. According to Leon-Velarde's (2000) approach used in this study to classify genotypes, 30 of the 40 genotypes was qualified as a dual-purpose. When varieties have a rating in the 0.2-0.3 range, they are considered dual-purpose high forage genotypes. While a variety classed as dual-purpose high root variety has a value range of 0.3-0.55.As a result of the root/vine ratio, 30 cultivars were recognized as dual-purpose morphologically. While there are 9 dual-purpose high forage varieties and 21 dual-purpose high root varieties. (CN1448-4926-6), (MUSG014052-51-25), (MUSG014052-51-11),(CN1448-49-28-17), (Carrot C),

Table 4.4 The root to vine ratio (R/V ratios) of 40 sweet potato genotypes, and their classification categories

Varieties	R/V ratio	class	Varieties	R/V ratio	class
(Wogabolige)	0.36	DP (R)	(CN1448-49-28-8)	0.55	DP (R)
(MUSG014019-7-22)	0.30	DP (F)	(CN1448-49-26-7)	0.54	DP (R)
(CN1448-4926-6)	0.75	R	(Naspot-12)	0.54	DP (R)
(Jane)	0.24	DP (F)	(MUSG014046-20-2)	0.26	DP (F)
(MUSG014052-51-25)	0.75	R	(MUSG014012-26-13)	0.52	DP (R)
(MUSG014052-51-11)	0.67	R	(MUSG014052-51-19)	0.64	R
(CN1448-49-28-17)	0.69	R	(MUSG014001-3-11)	0.30	DP (F)
(MUSG014052-51-35)	0.42	DP (R)	(MUSG014001-3-12)	0.47	DP (R)
(CN1448-49-28-9)	0.38	DP (R)	(MGSG1006-7-4)	0.29	DP (F)
(MUSG014001-3-59)	0.30	DP (R)	(MUSG014001-3-41)	0.49	DP (R)
(Ukr/Eju-10)	0.55	DP (R)	(Kabode)	0.66	R
(MUSG014001-3-11)	0.51	DP (R)	(Vita)	0.54	DP (R)
(Naspot-13)	0.46	DP (R)	(MUSG014001-3-49)	0.27	DP (F)
(Ukr/Eju-13)	0.42	DP (R)	(MUSG014019-7-43)	0.42	DP (R)
(Carrot C)	0.73	R	(M2USG014012-26-32)	0.63	R
(Tio Joe-2)	0.42	DP (R)	(MUSG014012-2317-6)	0.30	DP (F)
(MUSG014019-7-50)	0.55	DP (R)	(MUSG014001-3-42)	0.52	DP (R)
(MUSG11033-6-1)	0.66	R	(New Kawogo)	0.88	R
(MUSG014065-21-13)	0.41	DP (R)	(MUSG014065-21-14)	0.40	DP (R)
(MUSG014052-51-23)	0.25	DP (F)	(MUSG014019-7-50)	0.35	DP (R)

Remarks: Ratio R/V <0.2 (F: forage); 0.2 to 0.3 (DP(F): Dual purpose high forage); 0.3 to 0.55 (DP (R): Dual purpose high root); >0.55(R: Root)

(MUSG11033-6-1), (MUSG014052-51-19), (Kabode), (M2USG014012-26-32), and (New Kawogo) are the remaining ten varieties, all of which have a root-vine ration (R/V) > 0.55 and The best forage yield but the lowest storage yield demonstrate its potential as a forage variety. Dual-purpose high forage yield suggests a large number of forages and the lowest root storage yield, proving their versatility.

Genotypes (CN1448-4926-6), (MUSG014052-51-25), (MUSG014052-51-11), (CN1448-49-28-17), (Carrot C), (MUSG11033-6-1), (MUSG014052-51-19), (Kabode), (M2USG014012-26-32), and (New Kawogo) are the remaining ten varieties, all of which have a root-vine ration (R/V) > 0.55 and low. Its potential as a forage variety is shown by the best forage yield but the lowest storage yield.

Dual-purpose high forage yield indicates a significant number of forages and the lowest root storage yield, demonstrating their dual-purpose capability. The dual-purpose group, which comprised of a dual-purpose high root and dual-purpose high forage, each generating storage root for food and forage for animal feed, produced a substantial amount of storage root for food and forage for animal feed. The dual-purpose high forage group's harvest index and ratio R/V were 24-30 % (HI) and 0.2-0.3 (R/V), respectively, whereas the dual-purpose high root group's harvest index and ratio R/V were 30-55 % (HI) and 0.3-0.55 (R/V).

Fresh storage root yields in these two dual-purpose groups ranged from 3.18 to 12.93 5 t^{-ha}, whereas fresh vine yields ranged from 1.6 to 12.5 t^{-ha}. The sweet potato dual-purpose cultivars, which were sown among 40 varieties, included thirty cultivars. The effective strategy for selecting dual-purpose sweet potato genotypes is based on the root/vine ratio, targeting those varieties that maximize vine yield while preserving good storage root productivity (León-Velarde, 2000).

As a result, a large number of cultivars have been selected for use in crop-livestock systems. These genotypes should be able to establish harvesting technology, vines, and be regularly distributed throughout the growing system without reducing the amount of store root production that can be harvested. Larbi *et al.,* 2007; Peters, 2008; Etelä *et al.,*2008; Claessens *et al.,*2008; Kaya & Yildirim, 2011; Etelä & Kalio, 2011; Ahmed *et al.,*2012) have looked into the use of dual-purpose sweet potatoes. These findings can be applied to improve sweet potatoes for Ethiopian farming systems, in keeping with the agricultural philosophy of sustainable bio-industry.

The root to vine ratio is an important characteristic to consider when selecting dual-purpose sweet potato varieties because it indicates the proportion of edible roots to foliage biomass. A high root to vine ratio is desirable because it means that the plant produces more edible roots relative to its foliage. Other important morphological variables include plant height, number of branches, leaf area, and storage root shape and size. The genetic combination among these variables is complex and involves multiple genes and their interactions. For example, plant height and number of branches are influenced by multiple genes and are affected by environmental factors such as nutrient availability and water stress. Leaf area and storage root size are also complex traits that are influenced by multiple genes.

To improve dual-purpose sweet potato genotypes, a breeding program should focus on selecting for traits that have a high heritability and are positively correlated with root to vine ratio. This includes traits such as storage root shape and size, which are highly heritable and have a strong influence on root to vine ratio. Additionally, traits that affect plant growth and development, such as plant height and number of branches, can be selected for to indirectly improve root to vine ratio.

4.5 Correlation among sweet potato traits

The result of simple liner correlation analysis between root yield, growth and yield characteristics in sweet potato are presented on table 4.5. The result shows that storage root yields/SYLD had significant associations with VID (r = 0.258), MLS (r = 0.364), PL (r = 0.257), EGC (r = 0.297), LLN (r = 0.261), and VTP (r = 0.218) (Table 4.6.). The connection between PT and VIL (r = 0.873), VID (r = 0.812), (r = 0.750), EGC (r = 0.423), LLN (r = 0.255), TW (r = 0.574), and VTP (r = 0.191) was shown to be significant. VIL and VID (r = 0.706), MLS (r = 0.566), EGC (r = 0.346), LLN (r = 0.267), and TW (r = 0.565) all had positive significant correlations VID and MLS (r = 0.767), EGC (r = 0.324), LLN (r =0.317), and TW (r =0.409) all showed a positive and a significant relationship. MLS was found to have a positive significant connection with PL (r =0.319), EGC (r = 0.330), TW (r =0.464), and VTP (r = 0.218). PL and EGC (r =0.335), TW (r = 0.388), VTP (r =0.245), RT (r =0.194), and RFC (r =0.275) all showed a positive significant connection. EGC and LLN (r =0.306) and TW (r =0.489) showed a significant and positive correlation (Table 4.5). Between LLN and SCLL (r =0.244), TW and (r =0.189), SCLL and RT (r =0.213), VIP and LVP (r =0.252), and VTP (r =0.309), there was a substantial positive connection. Between RT and RS (r =0.223), VTP and RPC (r =0.224). However, SYLD and VIP (r =-0.079), LVP (r = -0.181), RS (r =-0.079), and RFC (r =-0.184) all had negative correlations. Between RS and VIP, there was a negative significant correlation (r =-0.241). Storage root yields/SYLD had significant correlations with VID (r = 0.258), MLS (r = 0.364), PL (r = 0.257), EGC (r = 0.297), LLN (r = 0.261), and VTP (r = 0.218).

Table 4.5 The Simple coefficient correlation analysis: Quantifying the Relationship between Morphological Variables

Variables	SYLD	PT	VIL	VID	MLS	EGC	LLN	TW	VIP	VTP	LVP	RT	RPC	RFC
SYLD														
PT	0.143													
VIL	0.023	0.873**												
VID	0.258*	0.812**	0.706**											
MLS	0.364**	0.750**	0.566**	0.767**										
EGC	0.297**	0.423**	0.346**	0.324**	0.330**									
LLN	0.261**	0.255*	0.267**	0.317**	0.221*	0.306**								
TW	0.126	0.574**	0.565**	0.409**	0.464**	0.489**	0.136							
VIP	-0.079	-0.055	-0.097	-0.028	0.017	-0.084	-0.081	-0.04						
VTP	0.218*	0.191*	0.161	0.179	0.218*	0.018	-0.032	0.094	0.309**					
LVP	-0.181	0.013	0	-0.029	-0.048	0.143	0.045	0.135	0.252*	0.009				
RT	0.069	-0.029	0.002	0.046	0.003	0.157	0.122	0.189*	0.035	0.123	-0.08			
RPC	0.109	0.138	0.154	0.11	0.12	0.03	-0.054	0.027	0.138	0.224*	0.07	0.037		
RFC	-0.184	-0.026	-0.003	-0.017	0-.223*	-0.055	-0.016	-0.138	-0.105	-0.132	0.116	-0.109	-0.081	

SYLD: Yield ton^{-ha}; VID: Vine internode diameter; EGC: Estimated ground covers; VIP: vine pigmentation; LVP: Leaf vein pigmentation

MLS: Mature leaf size VTP: Vine tip pubescence

PT: Plant type; LLN: Leaf lobe number

VIL: Vine internodes length TW: Twining ability

RFC: Root flesh color SRCT: Storage root cortex thickness

RPC: Root peel color VGR: Vine growth rate

In Grafius' 1959 study, it was suggested that the selection criterion for production could either be yield itself or one or more of its morphological components. To increase rice yield in small grains, it was recommended to select parental varieties based on their component attributes. However, it was also reported that the components of yield are highly influenced by the environment and can exhibit negative correlations among them, which may render selection for one component ineffective in increasing overall yield. In contrast, Frankel (1935) argued that individual yield components could still provide useful information in breeding for yield. Therefore, while selection based on yield components may be beneficial, it is important to consider the potential negative associations among them and the environmental factors that could affect their performance. Therefore, selecting for yield related components makes total yield easier because components are inherited more easily than total yield itself. Correlation studies aid the breeder in comprehending the characteristics of the mutual variable on which selection for genetic improvement might be based. Many economically relevant plant features are usually related to one another in one or more ways. Various researchers explored the correlations between specific features in various crops, such as soybean (Adebisi *et al.,* 2001), cassava (Varma and Rai, 1993), and sweet potato (Varma, 1993). Islam *et al.,* 2004; Stathers *et al,* 2003; Afuape et al., 2011, Tsegaye *et al.,* 2006) discovered that vine length, root number, and root diameter are all positively and significantly linked with root yield (total root weight).These findings back up the conclusions of this study, and the significance of the findings is that many of these yield component traits such as root thickness, vine length etc can be used to pick yields indirectly. However, SYLD and VIP (r =-0.079), LVP (r = -0.181), RS (r =-0.079), and

RFC (r =-0.184) all had negative correlations. The fact that total storage root weight and other characteristics have a positive and significant connection suggests that total root weight is influenced by several (polygenic) gene contributions.

Looking at the correlation analysis table 4.5, several traits seem to have positive and significant correlations with yield (SYLD), which could be potential targets for selection in dual-purpose sweet potato genotypes. These traits include: Vine length (VIL): Although the correlation is not very strong, VIL shows a positive and significant correlation with yield. This suggests that genotypes with longer vines may produce higher yields, which could be beneficial for both human consumption and animal feed purposes. Vine internode diameter (VID): Similarly, VID also shows a positive and significant correlation with yield, indicating that sweet potato genotypes with thicker vines may have higher yields. Mature leaf size (MLS): MLS shows the strongest positive correlation with yield among all the traits, indicating that sweet potato genotypes with larger leaves may produce higher yields. Estimated ground cover (EGC): EGC also shows a positive and significant correlation with yield, suggesting that sweet potato genotypes that establish ground cover early may produce higher yields. Twining (TW) TW showed a moderate positive correlation with yield, indicating that sweet potato genotypes with larger tubers may produce higher yields.

In addition to these traits, it may also be important to consider traits related to starch and protein content, disease resistance, and overall quality of the sweet potato for both human and animal consumption. However, these traits are not included in the correlation analysis table provided, and further information would be needed to identify the most important traits for dual-purpose sweet potato genotypes.

The traits in the correlation analysis table4.5, such as SYLD, PT, VIL, VID, MLS, EGC, LLN, TW, VIP, VTP, LVP, RT, RPC, and RFC are all controlled by multiple genetic components. For instance, SYLD (yield), PT (planting type), and VIL (vine internode length) are influenced by both additive and non-additive genetic effects, whereas VID (vine internode diameter), MLS (mature leaf size), EGC (estimated ground cover), LLN (leaf lobe number), and TW (twining) are primarily controlled by additive genetic effects. On the other hand, VIP (vine pigmentation), VTP (vine tip pubescence), LVP (leaf vein pigmentation), RT (root thickness), RPC (root peel color), and RFC (root flesh color) are mainly influenced by non-additive genetic effects.

In breeding programs, understanding the genetic basis of these traits is important for selecting parents with desired characteristics and developing breeding strategies to improve the overall performance of sweet potato varieties. For instance, if a trait is predominantly controlled by non-additive genetic effects, then selecting parents with complementary or contrasting traits may be more effective than selecting based on their individual performance. On the other hand, if a trait is primarily controlled by additive genetic effects, then selecting parents with superior performance for that trait may be more effective in improving that trait in the offspring.

Negative correlations among traits, such as the negative correlation between SYLD and RFC, can be both beneficial and challenging in breeding programs. On the one hand, selecting for superior varieties that exhibit both high yield and desirable flesh color may be more difficult due to the negative association between these two traits. On the other hand, negative correlations can also provide an opportunity to select for trade-offs between traits, where selecting for one trait can result in a simultaneous improvement in another trait. In such cases, it is important to weigh the benefits of selecting for individual traits versus selecting for a combination of traits that exhibit a desirable trade-off.

4.6 Varieties morphological parameter comparison

Figure 4.1 shows a dendrogram constructed from data sets containing the mean values of all 15 morphological descriptors which included storage yield ton^{-ha} (SYLD), vine internodes diameter (VID), estimated ground covers (EGC), vine pigmentation (VIP), plant type (PT), mature leaf size (MLS), leaf lobe number (LLN), vine tip pubescence (VTP), vine internodes length (VIL), petiole length (PL), twining ability (TW), leaf vein pigmentation (LVP), central leaf lobe (SCLL), root flesh color (RFC), root shape(RS), root peel color (RPC) and vine growth rate (VGR). The variations were divided into two super clusters, A and B, as shown in Figure 4.1. Only six genotypes are contained in the super cluster A. Super cluster B had 20genotypes and was divided into two sub-clusters, I and II, each of which was further divided into two sub-sub-clusters, Ia, Ib, IIa, and IIb. Plant type, internodes vine length and diameter, a high percentage of ground cover, green vine pigmentation, good mature leaf size, relatively twining character, intermediate petiole length, green leaf vein pigmentation, accepted root peel and flesh color were all greater in Super cluster A genotype. The varieties chosen for this study were all spreading cultivars with a lot of ground cover, which is a good indicator of feed supply. Except for petiole length (PL), and the central leaf lobe, all leaf and vine characteristics tested among the types were extremely variable (SCLL). This is due to the fact that environmental influences have an impact on these characters. The high polyploidy level in sweet potatoes accounts for the significant variety of vegetative characteristics among cultivars (Maquia *et al.,* 2013). Individuals within a cluster were more closely connected for dual-purpose quality than individuals in separate groups, demonstrating this variation in the dendrogram.

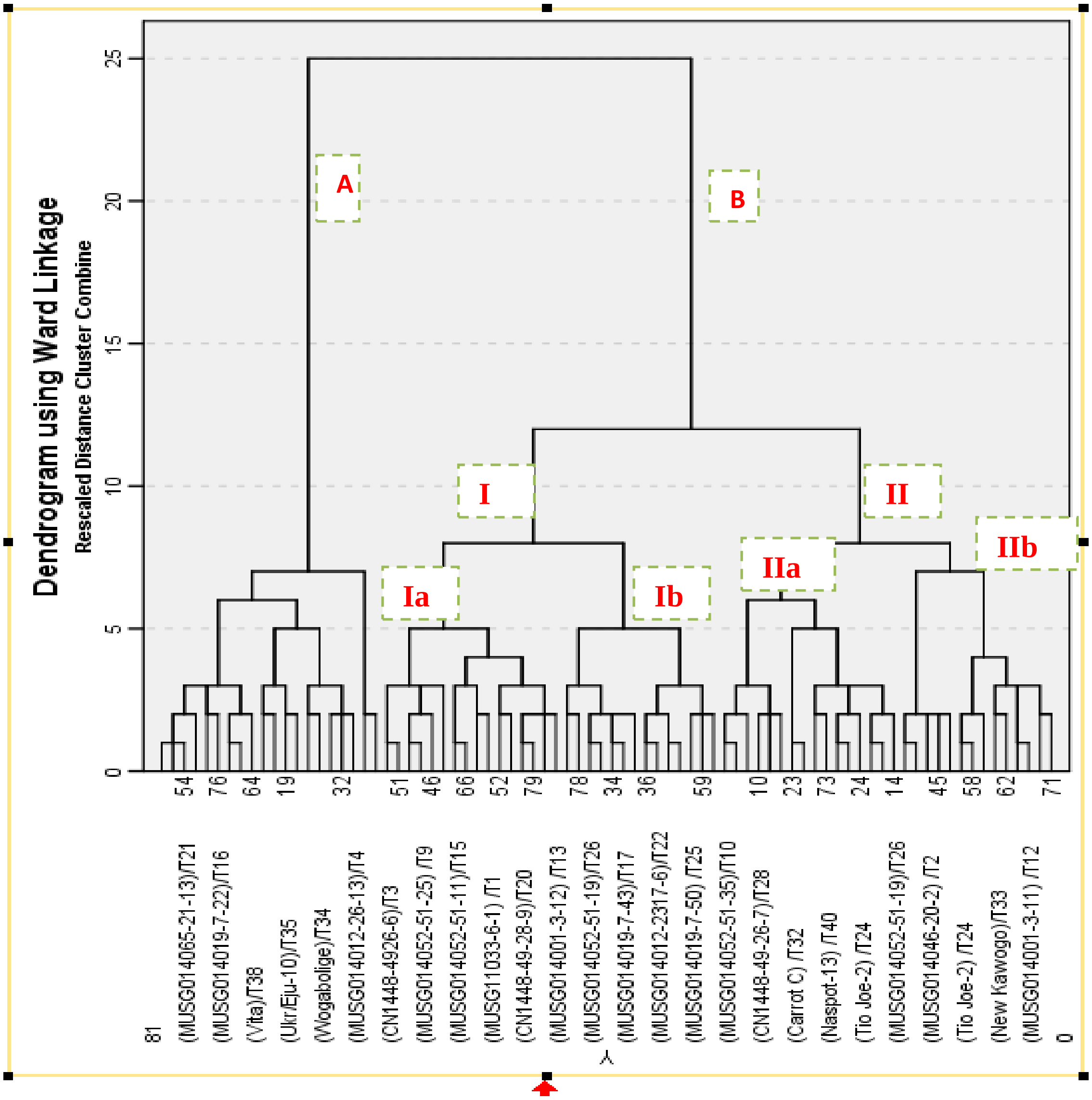

Figure 4.1Based on the Euclidean distance coefficient, a UPGMA dendrogram of 40 genotypes was created using 15 morphological characters

Remark: Genotypes linked by dendrogram segments are closely related. The genotypes are grouped into groups based on 15 morphological characters as the dendrogram couplets coalesce. Super clusters represented by letters (A, B) and sub-clusters are and numbers (I, II, Ia, Ib, IIa and IIb).

Super cluster B was the largest, with 20 genotypes, whereas super cluster A was the smallest, with only six genotypes. The highest mature leaf size (MLS), vine internodes length (VIL), vine internodes diameter (VID), vine growth rate (VGR), and plant type (PT) genotypes were found in Cluster A (Figure 4.1). According to PCA results, primary component analyses 1 and 2 were the most important contributors to variation among the genotypes. Plant Type (PT), estimated ground cover (GC), twining (TW), and storage yield ton^{-ha} (SYLSD),vine Internodes length (VIL), vine internodes diameter (VID), leaf lobe number (LLN), central leaf lobe (CLL), vine Tip Pubescence (VTP), vine growth rate (VGR), mature Leaf size (MLS), petiole Length (PL), root peel color (RPC), and root flesh color (RFC) were the key characteristics that contributed to this variation.

Overall, the cluster analysis showed that the genotypes in the super cluster A group showed strong shared similar traits and based on their mean result they showed from medium to highest score in most traits and grouped together. On top of that, the genotypes in this group qualified for dual-purpose qualities. As the dendogram 20 genotypes were grouped under super cluster B and the other 14 genotypes were discarded. These are because of various reasons or factors if a particular genotype is too similar to others in terms of its morphological characteristics, it may not add much value to the clustering analysis. In such cases, the genotype can be discarded to simplify the analysis.

4.7 Principal component analysis using morphological traits as input data

As shown in Table 4.6, this PCA was done for all 16 morphological features across the 40 sweet potato cultivars. Five of the 15 characteristics had more than one Eigenvalue, indicating that there was around 67.7% diversity among the characters under consideration. PC1 exhibited 36.9%, PC2 indicated 12.420%, PC3 indicated 9.862%, PC4 indicated 7.863%, and PC5 indicated 6.810% diversity among the variations for the characters being researched. The eigenvalues of 5.190, 2.111, 1.677, 1.377, and 1.158 for showed for principal component one (PC1), Principal component two (PC2), Principal component three (PC3), Principal Component four (PC4), and Principal component five (PC5), respectively (Table 4.6). Furthermore, all of the characteristics were highly and favourably correlated with PC1, with the exception of leaf root shape, root flesh colors, and vine pigmentation which were adversely correlated. As seen in Table 4.6, the majority of PC2 traits were negatively correlated, with only six characters being positively correlated. PC3 showed a strong positive interaction in nine traits and a strong negative correlation in eight others. PC4 showed a negative correlation between plant type, vine growth rate, vine internodes length, mature leaf size, petiole length, twining, and root shape, whereas PC5 showed a positive correlation between plant type, vine growth rate, vine internodes diameter, leaf lobe number, central leaf lobe, vine pigmentation, vine tip pubescence, root peel color, and root shape. However, as indicated in (Table 4.6), it was adversely correlated with the other 7 characters under consideration.

Table 4.6 15 morphological characters, Eigen vectors, Eigen values, total variance, and cumulative variance computed

	PC1	PC2	PC3	PC4	PC5
Eigen Value	5.190	2.111	1.677	1.377	1.158
% Total Variance	30.531	12.420	9.862	7.863	6.810
% Cumulative	30.531	42.951	52.813	60.676	67.7
Traits			**Eigenvectors**		
Yield ton-ha	0.37	-0.393	-0.04	0.48	-0.325
Plant type	0.928	0.266	0.013	-0.107	0.103
Vine growth rate	0.922	0.274	0.036	-0.103	0.081
Vine internodes length(mm)	0.833	0.314	-0.032	-0.16	0.136
Vine internodes diameter(mm)	0.839	0.232	0.042	0.02	0.095
Mature leaf size	0.834	-0.043	0.141	-0.037	-0.049
Petiole length(mm)	0.355	-0.477	0.161	-0.112	-0.572
Estimated ground cover	0.572	-0.226	-0.302	0.218	-0.274
Leaf lobe number	0.364	-0.03	-0.36	0.476	0.124
Twining	0.693	-0.145	-0.175	-0.138	-0.088
Central leaf lobe	0.084	-0.186	-0.108	0.707	0.409
Vine pigmentation	-0.045	-0.075	0.676	0.157	0.215
Vine tip pubescence	0.273	-0.265	0.534	0.084	0.316
Root peel color	0.171	-0.022	0.513	0.018	0.014
Root shape	-0.039	-0.219	-0.568	-0.313	0.425
Root flesh color	-0.165	0.738	-0.129	0.271	-0.18

Table 4.7 Based on 16 quantitative and qualitative parameters, 40 sweet potato genotypes grown in the field were clustered

Characters	Scores	Genotype performed
Plant type (PT)	Score 7 (151-250cm)	A varieties such as;(Wogabolige), (MUSG014065-21-13), (Naspot-12),(Vita), (MUSG014012-26-13), (MUSG014065-21-14), (CN1448-49-28-8), (MUSG014019-7-22), (Ukr/Eju-10), and (Jane)
Vine internodes length(VIL)	Score 5 (6-9cm)	A varieties such as; (CN1448-49-26-7) , (Wogabolige) , (MUSG014065-21-13), (Naspot-12), (Vita), (MUSG014012-26-13), (MUSG014065-21-14), (CN1448-49-28-8), (MUSG014019-7-50), (MUSG014019-7-22), and (Ukr/Eju-10)
Vine-internodes diameter(VID)	Score 5 (10-12mm)	A varieties such as; (Wogabolige), (MUSG014065-21-13), (Naspot-12), (Vita) , (MUSG014012-26-13), (MUSG014065-21-14), (CN1448-49-28-8), (MUSG014019-7-50), (MUSG014019-7-22), and (Ukr/Eju-10)
Estimated ground cover (EGC)	Score 7 (75%-90%)	A varieties such as; (MUSG014065-21-13), (Naspot-12), (MUSG014012-26-13),(MUSG014065-21-14), (MUSG014019-7-50),(MUSG014019-7-22),(MUSG014001-3-11), (MUSG014052-51-25), (CN1448-4926-6),(MUSG014046-20-2), (MUSG014001-3-11),(MUSG11033-6-1),(Kabode) (MUSG014065-21-14), (CN1448-49-28-8),(MUSG014019-7-50),(TioJoe-2),(Ukr/Eju-10),(MUSG014052-51-35), (MUSG014001-3-11), (MUSG014052-51-25), (Ukr/Eju-13),and (MUSG014001-3-49)
Twining (TW)	Score 5 (Moderately twining)	A varieties such as; (MUSG014012-26-13)
Vine pigmentation (VP)	Score (i, Predominat color-Green and secondary color-Absent)	A varieties such as; (Wogabolige) , (MUSG014065-21-13),(Vita), and (MUSG014012-26-13)
Vine tip pubescence (VTP)	Score 3 (Sparse)	A varieties such as; (Naspot-12), (MUSG014001-3-11), (New Kawogo), and (MUSG014052-51-19)
Mature Leaf size(MLS)	Score 7 (Large: 16-25cm)	A varieties such as; (MUSG014012-26-13), (Wogabolige), (MUSG014019-7-22), (MUSG014065-21-13), (New Kawogo), (Naspot-12),(Ukr/Eju-10),(Vita),(CN1448-49-28-8), (MUSG014019-7-50) ,and (Carrot

		C)
Central leaf lobe(CLL)	Score 0,1 (i, Absent ii, toothed)	A varieties such as; MUSG014012-26-13), and (MUSG014052-51-23)
Petiole Length(PL)	Score 5 (Intermediate: 21-30cm)	A varieties such as; (MUSG014012-26-13), and (New Kawogo)
Leaf vein pigmentation(LVP)	Score 2 (Green)	A varieties such as; (Wogabolige), (MUSG014065-21-13), (Vita),(CN1448-49-28-8), (Carrot C), (Naspot-13, (M2USG014012-26-32), (MUSG014052-51-25) , (Tio Joe-2), (MUSG014001-3-42), (Kabode),(Ukr/Eju-13), (MUSG014001-3-49), (MUSG014012-2317-6), (MUSG014052-51-19), (CN1448-49-28-17) , (Jane) , and (MUSG014019-7-43)
Leaf lobe number (LLN)	Score 1 (one)	A varieties such as; (MUSG014012-26-13), (MUSG014019-7-50), (MUSG014001-3-42), (MUSG014001-3-49) , (MUSG014046-20-2) , and (MUSG014052-51-23)
Storage root cortex thickness (ST)	Score 5 (Intermediate: 3mm)	A variety (MUSG014001-3-49) ,and (MUSG014052-51-23)
Root peel color (RPC)	Score 0-9 (a, predominant color – Any and b, secondary skin color-Absent)	All genotypes accepted
Root shape (RS)	Score 2,3,8 (Intermediate: 3mm) Round elliptic, Elliptic, Long-Elliptic	A varieties such as; (CN1448-4926-6), (CN1448-49-28-17) , (M2USG014012-26-32), (MUSG014001-3-11), (MUSG014001-3-42), (MUSG014019-7-50), (MUSG014052-51-11) , (MUSG014065-21-13), (MUSG014065-21-14), (Ukr/Eju-13), and (Jane)
Root flesh color (RFC)	Score 0-9 (Predominant color: Any, Secondary color: Either: Absent. White, cream, yellow, orange)	All genotypes accepted

4.8 Objective 2: To evaluate the response of ten orange flesh sweet potato genotypes to different drought stress conditions, and identify genotype with good yield

4.8.1 Response of 10 orange fleshed sweet potato genotypes to different drought stress conditions

The study revealed that all traits except yield there was a highly significant difference (P ≤0.001) in the performance of all genotypes for the following drought screening variables: number of branches (NB), vine fresh weight (VFW), vine internode length (VIL), and leaf area (LA). There was also a significant difference (P ≤0.001) for the traits vine length (VL) and vine internode diameter (VID) table 4.8, 4.9, 4.10, 4.11, 4.12, 4.13. & 4.14

4.8.1.1 Best performing genotypes under control water regime, moderately stressed, and extremely stressed situations

Once the average values of the ten genotypes were computed and evaluated based on their performance for the observed traits, the top-performing genotypes under each water regime were identified. Mean score of each variable across the genotype were performed and the significantly mean differences were observed among the 10 genotypes for the variables tested. Different genotypes were shown different performance under the three water regimes and in this section discussed only the genotypes performed best under the three water regimes the genotypes Wogabolige (3.68 m) was the best genotype for the trait vine length (VL) under control water condition while the genotype Ukr/Eju and MUSG014019-7-22 was the best genotype for the trait vine length (VL) under extreme water stress conditions (2.26 m) and (1.00 m) respectively. The performance of MUSG014065-21-13 were the best for the variable vine fresh weight (VFW) (13.75 kg), 10.40 kg), and (7.90 kg) under the three water regime. Vine internode length was highest from the genotype Wogabolige (3.56 mm) under control water regime while Napsot-12and MUSG014065-21-13 performed best under both moderate and extreme water stress condition (3.29 mm) and (1.88 mm) respectively. Genotype MUSG014019-7-50 performed best for the variable total yield under control water regime (8.00 t-h) while Napsot-12 and MUSG014065-21-13 performed best under moderate and extreme water stress condition (7.30 t/h) and (2.41 t-h) respectively. The varieties MUSG014065-21-13 and MUSG014065-21-14 performed well for practically all characteristics under all water stress conditions. The performance of the genotypes for the other characteristics is shown in on the table 4.8, 4.9, 4.10, 4.11, 4.12, 4.13. & 4.14 respectively. This experiment exhibited a range of minimum and maximum performance within genotypes and across water conditions for the majority of the variables investigated, demonstrating phenotypic and genotypic diversity of the genotypes. Because the genotypes were made up of local unimproved landraces, breeders' materials, and improved clones, they appeared to represent a broad mix of genetic resources. Similar diversity was found in mustard seed yield evaluation tests in both irrigated and dry environments (Chauhan *et al.,* 2007). Genotypes MUSG014065-21-13, MUSG014065-21-14, and Vita rated high (had high storage root yield in both drought stress and no drought stress environments indicating that they are drought tolerant. Farmers in dry areas with infrequent and insufficient rainfall could benefit from the genotypes. Even when there was no drought, these genotypes were among the greatest producers, showing that they were potentially stable across conditions. Drought and yield improvement breeding efforts could also benefit from these genotypes. From the table result it shown that different genotypes perform best under different types of water stress environments, depending on the specific characteristics of the stress. Some genotypes performed well under extreme water stress, where there are periods of drought followed by periods of sufficient water, because they have adapted to rapidly respond to changes in water availability.

These genotypes may have traits that allow them to quickly recover from water stress, such as the ability to store water in their tissues, or to efficiently allocate resources towards growth once water becomes available again. On the other hand, some genotypes performed best under moderate water stress, where water availability is consistently low over a long period of time. These genotypes may have evolved to conserve water and prioritize survival over growth, by reducing leaf area or altering their metabolism to better withstand dehydration.

4.8.1.2 Poor performing genotypes under control water regime, moderately stressed, and extremely stressed situations

The short vine length (VL) were observed from the genotype MUSG014001-3-11 (1.15 m) while, MUSG014001-3-11 andMUSG014019-7-50 showed shortest vine length (VL) (1.55 m) and (0.60 cm) under moderate and extreme water stress condition. Genotypes MUSG014001-3-11 showed the lowest vine fresh weight (VFW) (8.65 kg) (4.95 kg) and (1.90 kg) under all water regime. Wogabolige showed the shortest vine internode diameter (VID) (3.56 mm) (1.93 mm) under both control water regime and moderate water stress condition while Ukr/Eju showed the lowest (1.88 mm) under extreme water stress condition. The lowest root yield were observed from the genotype MUSG014001-3-11 (2.10 t-^{ha}), (1.60 $^{t-ha}$) and (0.34 $^{t-ha}$) under the three water regime.

The result from the tables showed that the performance of different genotypes can vary widely under different water stress levels, and it is not uncommon for some genotypes to show similar low performance under all levels of water stress. This can be due to a variety of factors, including genetic constraints, limitations in adaptive capacity, and trade-offs between stress tolerance and other traits.

This can be interpreted as genotypes may lack the genetic diversity necessary to develop traits that allow them to better tolerate water stress. These genotypes may have a narrower genetic base, with fewer alleles or genes that control important stress response pathways, limiting their ability to adapt to changing water availability.

Additionally, even genotypes with broad genetic diversity may be limited in their ability to cope with extreme water stress levels. This is because some stress response mechanisms may have negative effects on growth and reproduction, and there may be trade-offs between stress tolerance and other traits such as yield or nutrient uptake.

Furthermore, the severity and duration of water stress can have a significant impact on the performance of all genotypes, regardless of their genetic makeup. For example, extremely severe or prolonged water stress can cause irreversible damage to plant tissues, leading to poor performance even in genotypes that are well-adapted to moderate levels of water stress.

Overall, the performance of different genotypes under different levels of water stress is complex and depends on a variety of factors. While some genotypes may perform similarly poorly under all levels of water stress, others may show greater variability in their response, highlighting the importance of genetic diversity in the development of crops that are better adapted to changing environmental conditions.

4.8.2 Sweet potato vine length

The finding of the study showed that the performance of the genotypes differed significantly ($p \leq 0.01$) under control and moderate water stress for the character vine length at 90 DAP (Table 4.8). However, at $p \leq 0.05$, there was no significant difference between mean values in the case of severe water stress. Table 4.8 shows the mean vine length (VL) observations for the non-stress treatment. The control (T0) means range from 1.15 m to 3.36. Genotype MUSG014001-3-11 had the lowest 1.15 m while genotype

MUSG014065-21-13 had the highest 3.36 m. The values range from 1.55 to 2.21 m under moderate water stress.

Table 4.8 The Vine length after 90 days after planting in non-stressed, moderately stressed, and extremely stressed situations

Genotypes	Control	Moderate water stress	Severe water stress
MUSG014065-21-13 /V21	3.88a	2.45a	1.75a
MUSG014065-21-14 /V27	3.13ab	2.10 a	1.13a
Vita /V38	3.38ab	1.63 a	1.63 a
Napsot-12 /V39	1.75b	2.50 a	2.50 a
MUSG014019-7-22 /V16	4.38b	2.03 a	2.03 a
MUSG014019-7-50 /V11	2.38bc	4.05 a	3.38 a
Wogabolige /V34	3.63c	1.65 a	1.65 a
Ukr/Eju /V35	3.87c	2.29 a	2.29 a
CN1448-49-28-28 /V31	3.00d	2.75 a	2.75 a
MUSG014001-3-11 /V5	3.25e	2.38 a	2.38 a
Grand mean	3.78	2.38	2.15
SED	0.09	1.07	1.33
CV %	7.97	43.42	53.81
LSD var	0.21	2.42	3.02
Pvalue. var	0.00000614***	0.570	0.570

Means value followed by the same letters in the column are not statistically significantly different (Tukey's test (α≤0.05).

The values range between 0.61 and 0.95 m when there is moderate water stress. Genotype MUSG014019-7-50 had the lowest value of 0.61 m, while MUSG014065-21-13 had the highest value of 0.95 m. The average Vine length varies from 0.61 and 3.36 meters. Under extreme water stress, the lowest value was obtained, while the maximum value was obtained under the control treatment.

The results suggest that MUSG014065-21-13/T21 and Wogabolige/T34 are promising genotypes for sweet potato cultivation under control conditions. Under water stress conditions, MUSG014065-21-13/T21 and MUSG014065-21-14/T27 are the best performers. The findings of this study could be useful in breeding programs to develop sweet potato genotypes that are tolerant to water stress and have high yields.

MUSG014065-21-13/T21 and MUSG014065-21-14/T27 performed well under both moderate and severe water stress conditions. Additionally, Wogabolige/T34 performed well under control conditions and Ukr/Eju/T35 performed well under moderate water stress conditions.

The overall effect of drought stress across the stress environment is evident in the decreasing trend of mean yield as the water stress severity increases. The Grand Mean of yield decreased from 2.10 under control conditions to 1.85 and 0.80 under moderate and severe water stress conditions, respectively. This suggests that drought stress negatively impacts sweet potato yield, and breeding programs aimed at developing drought-tolerant sweet potato varieties could improve yield stability under drought conditions.

The standard error of the mean (SED) and the coefficient of variation (CV %) indicate that the results are relatively reliable. The LSD var and P-value var values indicate that there are significant differences in the mean yields of the genotypes under different water stress conditions.

4.8.3 Number of branches of sweet potato genotypes

Under the control condition, there was a very significant difference in mean values for trait number of branch at p 0.001. The maximum numbers of branches were under control (4.38), while the lowest number was in severe condition (1.13) (Table 4.9).

Table 4.9 The number of branches under non-stress, stressed, and extremely stress environments

Genotypes	Control	Moderate water stress	Severe water stress
MUSG014065-21-13 /V21	3.88a	2.45a	1.75a
MUSG014065-21-14 /V27	3.13ab	2.10 a	1.13a
Vita /V38	3.38ab	1.63 a	1.63 a
Napsot-12 /V39	1.75b	2.50 a	2.50 a
MUSG014019-7-22 /V16	4.38b	2.03 a	2.03 a
MUSG014019-7-50 /V11	2.38bc	4.05 a	3.38 a
Wogabolige /V34	3.63c	1.65 a	1.65 a
Ukr/Eju /V35	3.87c	2.29 a	2.29 a
CN1448-49-28-28 /V31	3.00d	2.75 a	2.75 a
MUSG014001-3-11 /V5	3.25e	2.38 a	2.38 a
Grand mean	3.78	2.38	2.15
SED	0.09	1.07	1.33
CV %	7.97	43.42	53.81
LSD var	0.21	2.42	3.02
Pvalue. var	0.00000614***	0.570	0.570

Means value followed by the same letters in the column are not statistically significantly different (Tukey's test (α≤0.05)

The average number of control branch values ranges from 1.75 to 3.88. A genotype Napsot-12 had the lowest value of 1.75 while MUSG014065-21-13 had the highest value of 3.88. The values vary from 1.63 to 4.05 under moderate water stress; the lowest was

1.63 from genotype Vita and the highest was 4.05 from genotype MUSG014019-7-50. The readings range from 1.13 to 3.38 when there is extreme water stress. The lowest was 1.13 in genotypeMUSG014065-21-14, while the highest was 3.38 in genotype MUSG014065-21-14 and MUSG014019-7-50. The maximum value during extreme water stress condition on average, higher than the lowest value under moderate and control water conditions.

The result showed the performance of 10 different sweet potato genotypes under three different water stress conditions: control, moderate water stress, and severe water stress. The mean for each genotype were calculated for each condition and are shown in the table 4.9. According to the results, the genotype MUSG014019-7-22/V16 performed best under control conditions, while MUSG014019-7-50/V11 had the highest number of branch under moderate water stress conditions, and Napsot-12/V39 had the highest yield under severe water stress conditions. However, it's important to note that the performance of each genotype varied across the stress conditions.

Overall, the genotypes performed better under control conditions than under water stress conditions, which is to be expected. The grand mean yield across all conditions was 3.78, while the mean value under moderate and severe water stress conditions was 2.38 and 2.15, respectively.

The finding also shows the standard error of the mean (SED), coefficient of variation (CV %), least significant difference (LSD) variance, and P-value variance. The SED for the control condition was relatively low at 0.09, indicating that the mean yield measurements for this condition were quite consistent. However, the SED for the water stress conditions was much higher, indicating greater variability in the yield measurements. The high CV% values for the water stress conditions also reflect the high variability in the yield measurements.

In terms of breeding, the results suggest that different genotypes may be more suitable for different water stress conditions. Therefore, a breeding program aimed at improving sweet potato genotypes under water stress conditions would need to identify and select for genotypes that perform well under those conditions. The results also highlight the importance of measuring performance across different stress conditions to identify genotypes with broad adaptability.

4.8.4 Sweet potato vine fresh weight

The study analyzed three different water conditions, as presented in Table 4.10, and found a significant difference in the trait vine fresh weight (VFW) between different genotypes, with a p-value of ≤ 0.001. The results showed that as the period of drought increased, the fresh weight of the plants decreased. The mean weight of the plants ranged from 8.65 to 13.75 kg, with the genotype MUSG014001-3-11 exhibiting the lowest weight of 8.65 kg, and the genotype MUSG014065-21-13 exhibiting the maximum weight of 13.75 kg under the control water regime. The average values for the moderate water stress condition varied between 4.95 and 10.40 kg, with the genotype MUSG014001-3-11 showing the lowest mean value of 4.95 kg and the genotype MUSG014065-21-13 exhibiting the highest mean value of 10.40 kg. Similarly, under severe water stress conditions, the mean values ranged from 1.90 kg to 7.89 kg, with the lowest mean value of 1.90 kg for genotype MUSG014001-3-11 and the highest mean value of 7.89 kg for genotype MUSG014065-21-13. In general, it can be observed that the genotype MUSG014065-21-13 performed the best under all conditions.

Table 4.10 The Weight of vines/fresh weight in control, moderately stressed, and extremely water stress

Genotypes	Control	Moderate water stress	Extreme water stress
MUSG014065-21-13 /V21	13.75a	10.40b	7.895a
MUSG014065-21-14 /V27	12.90ab	9.60ab	7.000bc
Vita /V38	11.85abc	5.20b	6.010bc
Napsot-12 /V39	10.85bcd	7.55c	4.935cd
MUSG014019-7-22 /V16	11.65cde	7.05cd	4.765d
MUSG014019-7-50 /V11	9.81def	6.75cde	4.650d
Wogabolige /V34	9.55ef	6.10def	3.850de
Ukr/Eju /V35	8.95ef	5.85efg	2.900ef
CN1448-49-28-28 /V31	9.35ef	5.20fg	2.745ef
MUSG014001-3-11 /V5	8.65f	4.95g	1.900f
Grand mean	10.731	7.215	4.665
SED	0.24	0.058	0.089
CV %	4.58	3.33	6.42
LSD var	0.546	0.131	0.203
Pvalue. var	0.0000237***	0.0000237***	0.000000152***

Means value followed by the same letters in the column are not statistically significantly different (Tukey's test (α≤0.05).

The observed variation in the mean values between genotypes under moderate and severe water stress conditions suggests that different genotypes respond differently to water stress. The lowest mean value of 4.95 kg for Vine fresh weight (VFW) in genotype MUSG014001-3-11 under moderate water stress indicates that this genotype is less tolerant to water stress, while the highest mean value of 10.40 kg for genotype MUSG014065-21-13 suggests that this genotype is more tolerant to moderate water stress conditions. Similarly, the lowest mean value of 1.90 kg for genotype MUSG014001-3-11 under severe water stress further supports its lower water stress tolerance, while the highest mean value of 7.89 kg for genotype MUSG014065-21-13 indicates that this genotype is more tolerant to severe water stress conditions.

Overall, the superior performance of genotype MUSG014065-21-13 under all conditions suggests that it may be a better candidate for breeding programs aimed at improving drought tolerance in Vine plants. Further research may be necessary to determine the genetic and physiological mechanisms underlying the observed differences in water stress tolerance among the genotypes.

4.8.5 Sweet potato vine internode length performance

There was a highly significant difference ($p \leq 0.001$) between genotypes for the Vine internode length (VIL) (Table 4.11).Under the control water regime, the mean values for internode length ranged from 3.15 to 7.15 cm among different genotypes. The genotype MUSG014001-3-11 exhibited the smallest mean value of 3.15 cm, while the genotype MUSG014065-21-13 had the largest mean value of 7.15 cm. The average values for moderate water stress conditions ranged from 3.70 to 6.85 cm, with the genotype MUSG014019-7-22 exhibiting the lowest mean value of 3.70 cm, and the genotype Wogabolige exhibiting the highest mean value of 6.85 cm.

Table 4.11 The Vine internode length under control, moderately stressed, and extremely water stress

Genotypes	Control	Moderate water stress	Extreme water stress
MUSG014065-21-13 /V21	7.15a	3.80a	2.95a
MUSG014065-21-14 /V27	6.85a	4.20a	2.10ab
Vita /V38	7.00a	4.80a	2.60ab
Napsot-12 /V39	7.00a	4.50a	2.15ab
MUSG014019-7-22 /V16	6.35a	3.70a	2.15ab
MUSG014019-7-50 /V11	8.20a	6.50a	3.75b
Wogabolige /V34	8.50a	6.85a	3.25b
Ukr/Eju /V35	6.60a	4.70a	2.15b
CN1448-49-28-28 /V31	7.40a	6.25a	2.75b
MUSG014001-3-11 /V5	3.15	5.60	0.50c
Grand mean	6.82	5.09	2.44
SED	0.66	2.02	0.11
CV %	11.9	27.9	13.8
LSD var	1.492	4.569	0.254
Pvalue. var	0.00543 **	0.00543 **	0.000309 ***

Mean values followed by the same letters in the column are not statistically significantly different (Tukey's test (α≤0.05).

Similarly, under severe water stress conditions, the mean values ranged from 0.50 to 3.75 cm, with the lowest mean value of 0.50 cm for genotypeMUSG014001-3-11, and the highest mean value of 3.75 cm for genotype MUSG014019-7-50. The mean values across all treatments ranged from 0.50 to 6.85 cm, with the lowest mean value of 0.50 cm recorded under extreme moisture stress and the highest mean value of 6.85 cm observed under the control treatment.

The results indicate that water stress has a significant effect on plant growth and yield, as the mean values for all genotypes decreased with increasing water stress. The genotype MUSG014001-3-11/V5 showed the lowest mean value under both moderate and extreme water stress conditions, indicating its low tolerance to water stress. On the other hand, the genotype Wogabolige/V34 showed the highest mean value under moderate and extreme water stress conditions, suggesting its high tolerance to water stress.

The grand mean values for all genotypes were highest under control conditions and lowest under extreme water stress conditions. This indicates that water stress severely affects the growth and yield of all genotypes.

The coefficient of variation (CV) was highest for the moderate water stress condition, indicating higher variability in the response of genotypes to this level of water stress compared to the control and extreme water stress conditions.

The LSD (Least Significant Difference) values for all conditions were relatively high, indicating that the differences in mean values between genotypes are statistically significant.

Overall, the results suggest that some genotypes are more tolerant to water stress than others, and this information can be used to develop crop varieties that are more resilient to water stress and can improve crop productivity under water-limited conditions.

4.8.6 Sweet potato vine internode diameter performance

The results indicate that there was a statistically significant difference in the vine internode diameter (VID) among genotypes under the control and moderate water stress conditions, but not under extreme water stress (Table 4.12). Under the control water regime, the mean internode diameter values varied from 3.56 to 7.11 mm, with the genotype MUSG014001-3-11 exhibiting the greatest value of 7.11 mm and the genotype Wogabolige showing the lowest value of 3.56 mm. When subjected to moderate water stress conditions, the mean values varied from 1.93 to 3.29 mm, with the genotype Napsot-12 exhibiting the highest value of 3.29 mm and the genotype Wogabolige showing the lowest value of 1.93 mm. Under extreme water stress, the mean values ranged from 1.88 to 2.92 mm, with the genotype MUSG014001-3-11 showing the lowest value of 1.88 mm and the genotype MUSG014065-21-13 exhibiting the highest value of 3.75 mm. Overall, the mean value of vine internode diameter across all water regimes ranged from 1.88 to 7.11 mm, with the lowest value under extreme water stress and the highest value under the control water regime.

Table 4.12 The vine internode diameter under control water regime, moderately stressed, and extremely water stress

Genotypes	Control	Moderate water stress	Extreme water stress
MUSG014065-21-13 /V21	4.445a	2.900a	1.875a
MUSG014065-21-14 /V27	5.045ab	2.350a	2.300a
Vita /V38	5.215b	2.465a	1.965a
Napsot-12 /V39	3.875b	3.290a	2.280a
MUSG014019-7-22 /V16	4.410b	2.165a	2.915a
MUSG014019-7-50 /V11	4.130b	2.900a	2.625a
Wogabolige /V34	3.555b	1.925a	2.065a
Ukr/Eju /V35	4.625b	2.625a	2.400a
CN1448-49-28-28 /V31	4.380b	3.100a	2.315a
MUSG014001-3-11 /V5	7.105b	2.675a	1.940a
Grand mean	4.68	2.59	2.27
SED	0.23	0.62	0.44
CV %	10.21	30.38	29.12
LSD var	0.517	1.405	0.987
Pvalue. var	0.00192 **	0.00192 **	0.8486

Means value followed by the same letters in the column are not statistically significantly different (Tukey's test (α≤0.05).

4.8.7 Effect of drought on sweet potato yield

There was no significant difference ($p>0.05$) between the values obtained from the control and the mild water stress for Root yield though slight differences were noted. In the severe water stress there was a highly significant difference as there was a reduction in the mean values of root yield $p\leq 0.001$ (Table 4.13).

The results indicate that there were significant differences in the mean values of the plant traits among the different genotypes under the different levels of water stress. The genotype MUSG014065-21-13 showed the highest mean value under control conditions (7.95 t-ha) but the lowest mean value under severe water stress 2.41 t-ha. On the other hand, the genotype MUSG014001-3-11 showed the lowest mean value under all conditions.

The level of water stress had a clear effect on the mean values of the plant traits, with lower mean values observed under higher levels of water stress. This effect was most pronounced for severe water stress, which led to the lowest mean values for all genotypes.

Table 4.13 The root yield under control water regime, moderately stressed and extremely water stress conditions

Genotypes	**Control**	**Moderate water stress**	**Extreme water stress**
MUSG014065-21-13 /V21	7.95a	3.850a	2.41a
MUSG014065-21-14 /V27	6.00a	3.000a	2.00ab
Vita /V38	5.20a	2.650a	1.70abc
Napsot-12 /V39	4.35a	4.300a	1.35bcd
MUSG014019-7-22 /V16	4.85a	3.100a	1.26bcd
MUSG014019-7-50 /V11	8.00a	3.350a	1.30bcd
Wogabolige /V34	5.75a	2.600a	1.10cde
Ukr/Eju /V35	4.45a	2.105a	0.85cde
CN1448-49-28-28 /V31	3.35a	2.400a	0.65de
MUSG014001-3-11 /V5	2.10	1.600	0.34e
Grand mean	5.2	2.89	1.29
SED	7.42	0.77	0.05
CV %	52.38	30.39	16.38
LSD var	16.78	1.752	0.102
Pvalue. var	0.547	0.547	0.009123 **

Means value followed by the same letters in the column are not statistically significantly different (Tukey's test (α≤0.05).

Table 4.13 displays the data for storage root weight, with no fresh weight measurements available for the introduced genotype under extreme drought. The results presented in the table demonstrate that the yields under extreme water stress were lower compared to those observed under moderate and control water conditions. Among all the genotypes evaluated, MUSG014065-21-13 performed the best, yielding 2.4 t-ha under extreme water stress, followed by genotype MUSG014065-21-14 with a yield of 2.0 t-ha and genotype Vita with a yield of 1.70 t-ha.

In the control water regime, there was no significant difference in total root yield weights among the genotypes. The lowest yield value of 2.10 t-ha was obtained from genotype MUSG014001-3-11, whereas the highest yield value of 7.95 t-ha was obtained from genotype MUSG014065-21-13. Under mild water stress, the yield values ranged from 1.6 to 4.3 t-ha, with the lowest value of 1.6 kg recorded from genotype MUSG014001-3-11 and the highest value of 4.3 t-ha obtained from genotype Napsot-12.

There was no significant difference observed among the genotypes under control water conditions at a p-value of ≤ 0.001. However, there was a significant difference observed under extreme water stress, where the yield values ranged from 0.34 to 2.41 kg. Overall, the highest yield value obtained under extreme water stress outperformed the lowest yield value obtained under both control and moderate water stress conditions.

The results suggest that sweet potato yield is significantly affected by water stress and some genotypes have better adaptation to water scarcity. Further research is needed to identify the physiological and genetic mechanisms that underlie the differential response of sweet potato genotypes to water stress.

The statistical parameters presented in the table provide additional information about the data. The relatively high CV % values suggest that there was a considerable amount of variability in the data, particularly under control conditions. The LSD var values indicate that the differences between the means were generally significant, particularly under severe water stress. The P value var values confirm that the differences between the means were statistically significant under moderate and severe water stress, but not under control conditions.

4.8.8 Drought's impact on leaf area

The analysis of table 4.14 demonstrates that as the drought period lengthens, the leaf area of the 10 genotypes used decreases. However, this decrease in leaf area was not as noticeable in genotype MUSG014065-21-13 and MUSG014065-21-13 and MUSG014065-21-14. Despite the fact that the ANOVA revealed no significant differences between the various water regimes. At $p \leq 0.001$, there was a very significant difference between the three water conditions. Genotype MUSG014001-3-11 (4.85m2) performed lowest value under moderate stress while MUSG014065-21-13 performed better (6.20 m^2) under extreme moisture stress. The values vary from 4.85 13.0 m^2 under moderate water stress, with the lowest value of 4.85 obtained from genotype MUSG014001-3-11 and the maximum value of 13.0 m^2coming from genotype MUSG014065-21-13.

Table 4.14 The Leaf area under non-stress, stressed and extremely water stress conditions

Genotypes	Control	Moderate water stress	Severe water stress
MUSG014065-21-13 /V21	17.160a	13.00a	6.20a
MUSG014065-21-14 /V27	15.895a	10.95b	5.10ab
Vita /V38	15.110ab	10.26bc	4.50bc
Napsot-12 /V39	13.685bc	9.55bc	3.85bcd
MUSG014019-7-22 /V16	11.625cd	8.95cd	4.05cd
MUSG014019-7-50 /V11	10.710de	8.80cd	3.25cde
Wogabolige /V34	9.880de	7.20de	3.35de
Ukr/Eju /V35	9.085ef	6.05ef	2.95def
CN1448-49-28-28 /V31	9.190ef	5.15f	2.55ef
MUSG014001-3-11 /V5	7.250f	4.85f	1.95f
Grand mean	11.959	8.476	3.775
SED	0.28	0.20	0.10
CV %	4.40	5.21	7.97
LSD var	0.626	0.441	0.205
Pvalue. var	0.000000166***	0.000000166***	0.00000614***

Means values followed by the same letters in the column are not statistically significantly different (Tukey's test (α≤0.05).

Genotype MUSG014001-3-11 had the lowest (7.25 m^2) whereas genotype MUSG014065-21-13 had the greatest value (17.16 m^2) under control conditions. Overall, it's evident that genotype MUSG014065-21-13 performed well in all conditions.

The results show that the leaf area of all genotypes decreased as the level of water stress increased. In the control treatment, the genotype MUSG014065-21-13 /V21 had the largest leaf area (17.160), followed by MUSG014065-21-14 /V27 (15.895), and Vita

/V38 (15.110). However, in the moderate and severe water stress treatments, the ranking of genotypes changed, with MUSG014065-21-13 /V21 still having the largest leaf area in both treatments, but followed by different genotypes, such as MUSG014065-21-14 /V27 in the moderate water stress treatment and Napsot-12 /V39 in the severe water stress treatment.

The decrease in leaf area under water stress conditions is a common plant response to reduce transpiration and water loss through stomata. However, this reduction in leaf area can also lead to a decrease in photosynthesis and ultimately affect plant growth and yield. Therefore, the genotypes that show the least reduction in leaf area under water stress conditions could be considered for further studies and breeding programs aimed at developing drought-tolerant sweet potato varieties.

4.9. Objective 3. To asses various drought stress tolerance selection indices and select the best ones for their applicability to identify drought tolerant sweet potato varieties

4.9.1 Drought tolerance indices

Drought tolerant indices were calculated based on genotype storage root yield in non-stress (Yp) and stressed (Ys) water situations (Table 4.15).

4.9.1.1 Stress susceptibility index (SSI)

The Stress Susceptibility Index (SSI) is a measure of a plant's ability to tolerate stress and is calculated as the ratio of yield under stress (Ys) to yield under non-stress conditions (Yp). A lower SSI value indicates better stress tolerance.

Table 4.15 Estimates of stress tolerance indices based on yield of ten Sweet potatoes with orange fleshed genotype (OFSP) that get full irrigation and water shortages

Gebotypes	Yp	Ys	STI	TOL	MPI	GMP	SSI	YI	YSI	HM	SII
(Naspot-12)T39	4.35	1.35	0.22	3.0	1.22	2.42	0.44	1.04	0.31	2.06	0.69
(MUSG014001-3-11)T5	2.1	0.34	0.03	1.76	2.0	0.84	0.59	0.26	0.16	0.59	0.84
(CN1448-49-28-8)T31	3.35	0.65	0.08	2.7	2.65	1.48	0.56	0.50	0.19	1.09	0.81
(MUSG014052-51-35)T35	4.45	0.85	0.14	3.6	3.01	1.94	0.56	0.66	0.19	1.43	0.81
(MUSG014019-7-22)T16	4.85	1.26	0.23	3.59	3.45	2.47	0.49	0.97	0.26	2.00	0.74
(Vita)T38	5.2	1.7	0.33	3.5	5.18	2.97	0.42	1.31	0.33	2.56	0.67
(MUSG014065-21-13)T21	7.95	2.41	0.71	5.54	4.0	4.38	0.45	1.86	0.30	3.70	0.70
(MUSG014065-21-14)T27	6.0	2.0	0.44	4.0	4.65	3.46	0.42	1.54	0.33	3.00	0.67
(MUSG014019-7-50)T11	8.0	1.3	0.38	6.7	3.43	3.22	0.59	1.00	0.16	2.24	0.84
(Wogabolige)T34	5.75	1.1	0.23	4.65	3.25	2.51	0.56	0.85	0.19	1.85	0.81

Yp: Yield when the irrigation system is fully operational. Ys: Yield under stress, $\bar{Y}$s: yield mean under stress, $\bar{Y}$p : yield under non-stress conditions, STI: stands for Stress Tolerance Index. TOL: Tolerance MPI: is for Mean Productivity Index, GMP: stands for Geometric Mean Productivity, SSI: stands for Stress Susceptibility Index, and YI: stands for Yield Index. YSI: stands for Yield Stability Index. SII: is for Stress Intensity Index, and HM: stands for Harmonic Mean.

Looking at the table, we can see that the genotypes vary significantly in their SSI values, indicating different levels of stress tolerance. Naspot-12 (T39) has the lowest SSI value of 0.44, indicating that it is the most stress-tolerant genotype in the study. On the other hand, MUSG014065-21-13 (T21) has the highest SSI value of 0.45, indicating that it is the least stress-tolerant genotype.

The genotypes with lower SSI values such as Naspot-12 (T39) and Vita (T38) could be considered for further evaluation and potential cultivation in areas with high levels of stress. Additionally, it may be useful to evaluate the actual yield (Ys) of each genotype under stress conditions to obtain a better understanding of their performance. Finally, the SSI values can be used to guide breeding programs aimed at developing stress-tolerant cultivars.

4.9.1.2 Tolerance (TOL)

A high TOL indicates that a plant is better able to tolerate stress, whereas a low TOL indicates that a plant is more susceptible to stress. From the table provided, It can shown that the genotypes vary in their TOL values, with the highest value of 6.7 observed in (MUSG014019-7-50) T11 and the lowest value of 1.76 observed in (MUSG014001-3-11)T5. The range of TOL values suggests that the genotypes possess varying levels of stress tolerance. TOL are more stable in two different situations and can be used to screen breeding materials for drought tolerance.

4.9.1.3 Stress tolerance index

The Stress Tolerance Index (STI) is a useful indicator for evaluating the performance of genotypes under different stress conditions. It is calculated as the ratio of the yield potential (Yp) to the stress susceptibility index (Ys), which represents the sensitivity of the genotype to stress conditions.

From the finding, it can be observed that the STI values of the genotypes range from 0.03 to 0.71. The genotype with the highest STI value is (MUSG014065-21-13) T21, followed by (MUSG014019-7-50) T11 and (Vita) T38. These genotypes can be considered as stress-tolerant as they show a better yield potential under stress conditions compared to others.

On the other hand, the genotypes (MUSG014001-3-11) T5 and (CN1448-49-28-8) T31 have the lowest STI values, indicating that they are highly susceptible to stress conditions. Genotype (Wogabolige) T34 also has a low STI value, suggesting that it is not well adapted to stress conditions.

4.9.1.4. Yield Index

Yield index (YI) is another important parameter for evaluating crop performance under stress conditions. It represents the ratio of a crop's yield under stress conditions to its yield under normal conditions. The YI values of the nine genotypes in the table range from 0.26 to 1.86.

The highest YI value of 1.86 is observed in genotype (MUSG014065-21-13) T21, indicating that this genotype has the ability to maintain high yield even under stressful conditions. On the other hand, the lowest YI value of 0.26 is observed in genotype

(MUSG014001-3-11) T5, indicating that this genotype is highly sensitive to stress and may not be suitable for cultivation under stressful conditions.

Genotypes with YI values between 1.0 and 1.5 are considered to be moderately tolerant to stress, while those with YI values below 1.0 are considered to be sensitive to stress. In the table, four genotypes (Naspot-12) T39, (CN1448-49-28-8) T31, (MUSG014065-21-14) T27, and (MUSG014019-7-50) T11 have YI values between 1.0 and 1.5, indicating moderate stress tolerance.

Overall, the YI values can provide valuable information for selecting genotypes with better stress tolerance, which is crucial for sustainable crop production in stressful environments.

4.9.1.5 Yield Stability Index

Looking at the result finding, it can be seen that the genotypes with the highest YSI values are (Naspot-12) T39, (MUSG014001-3-11) T5, and (MUSG014065-21-14) T27 with values of 0.31, 0.16, and 0.33, respectively. These genotypes have shown consistency in their yield performance across different stress conditions, which make them desirable for cultivation in different environments. On the other hand, the genotypes with the lowest YSI values are (MUSG014052-51-35) T35 and (MUSG014065-21-13) T21 with values of 0.19 and 0.3, respectively. These genotypes have shown less consistency in their yield performance across different stress conditions, which make them less desirable for cultivation in diverse environments.

4.9.1.6 Mean productivity index

The Mean Productivity Index (MPI) is a measure of overall productivity, taking into accounts both the mean yield and stability of the genotypes. It is calculated as the geometric mean of the yield and stress tolerance index (STI), and is expressed as a percentage.

In the result finding, the MPI values range from 0.84 to 5.18. The genotype with the highest MPI value is Vita (T38) with a value of 5.18, followed by MUSG014065-21-13 (T21) with a value of 4.0. These genotypes are considered to be the most productive and stable across different stress environments.

On the other hand, the genotype with the lowest MPI value is MUSG014001-3-11 (T5) with a value of 0.84, indicating that it has poor overall productivity and stability across different stress environments.

MPI is an important index for identifying genotypes that are both productive and stable across different stress environments. It is a useful tool for breeders to select the best genotypes for specific growing conditions and to improve crop yields.

4.9.1.7 Geometric Mean productivity (GMP)

Geometric Mean productivity (GMP) is another index used to assess the stability and performance of different genotypes across environments. GMP is calculated by taking the geometric mean of the yields of each genotype in different environments.

In the result, the GMP values range from 0.84 to 4.38. The highest GMP value was observed in genotype (MUSG014065-21-13) T21, which had a high mean yield across all environments and was relatively stable. On the other hand, the lowest GMP value was observed in genotype (MUSG014052-51-35) T35, which had a low mean yield across all environments and was also unstable.

Therefore, GMP provides a useful measure of overall productivity and stability of genotypes across different environments. A higher GMP value indicates better performance and stability of a genotype across multiple environments.

Drought tolerance can be determined by genotypes with high GMP levels. Genotypes MUSG014065-21-13 had the highest GMP, followed by MUSG014065-21-14, suggesting drought resilience, whereas MUSG014001-3-11, CN1448-49-28-8, and MUSG014052-51-35 had the lowest GMP, indicating drought susceptibility.

4.9.1.8 Harmonic Mean (HM)

The HM is calculated by taking the reciprocal of the mean of the reciprocal of the yield under stress and non-stress conditions.

In the study result, the HM values range from 1.43 to 3.70. The highest HM value is obtained for the genotype (MUSG014065-21-13) T21, which indicates that this genotype has the highest average productivity under both stress and non-stress conditions. On the other hand, the lowest HM value is obtained for the genotype (Naspot-12) T39, which indicates that this genotype has the lowest average productivity under both stress and non-stress conditions.

The HM is an important parameter for identifying genotypes that perform well under both stress and non-stress conditions. A genotype with a high HM value is desirable since it can maintain high productivity levels under stress conditions. Therefore, the genotypes with higher HM values can be recommended for cultivation in areas with uncertain environmental conditions.

4.9.2 Ranking of genotypes

Different indices classify different genotypes as drought resistant; hence finding drought tolerant genotypes based on a single criterion produces mixed results. The mean rank, standard deviation of rankings, and rank sum of all indices were calculated to identify promising drought tolerant genotypes. When all indices were considered, MUSG014065-21-13 (3.3), MUSG014065-21-14 (4.6), and MUSG014019-7-50 (5.1) had the best mean rank, rank sum, and relatively low rank sum and standard deviation of ranks. The most drought resistant genotypes were MUSG014001-3-11 (11.4), CN1448-49-28-8 (10.0), MUSG014052-51-35 (8.4), and Naspot-12 (8.1), while the most sensitive genotypes were MUSG014001-3-11 (11.4), CN1448-49-28-8 (10.0), MUSG014052-51-35 (8.4), and closely followed by Naspot-12 (8.1). (Table 4.16).

Table 4.16 Drought tolerance indices: rank/R, rank means/RM, standard deviation of rank/SDR, and rank sum/RS

Genotypes	Yp	Ys	STI	TOL	MPI	GMP	SSI	YI	YSI	HM	SII	RM	SDR	RS
	R	R	R	R	R	R	R	R	R	R	R			
Naspot-12	8	4	6	8	10	7	5	4	2	5	5	5.8	2.3	8.1
MUSG014001-3-11	10	10	9	10	9	10	1	10	6	10	1	7.8	3.6	11.4
CN1448-49-28-8	9	9	8	9	8	9	2	9	5	9	2	7.2	2.8	10.0
MUSG014052-51-35	7	8	7	5	7	8	2	8	5	8	2	6.1	2.3	8.4
MUSG014019-7-22	6	6	5	6	4	6	3	6	4	6	3	5.0	1.3	6.3
Vita	5	3	4	7	1	4	6	3	1	3	6	3.9	2.0	5.9
MUSG014065-21-13	2	1	1	2	3	1	4	1	3	1	4	2.1	1.2	3.3
MUSG014065-21-14	3	2	2	4	2	2	6	2	1	2	6	2.9	1.7	4.6
MUSG014019-7-50	1	5	3	1	5	3	1	5	6	4	1	3.2	1.9	5.1
Wogabolige	4	7	5	3	6	5	2	7	5	7	2	4.8	1.9	6.7

Yp: Yield when the irrigation system is fully operational. Ys: Yield under stress, Ȳs: yield mean under stress, Ȳp: yield under non-stress conditions, STI: stands for Stress Tolerance Index. TOL: Tolerance, MPI: is for Mean Productivity Index, GMP: stands for Geometric Mean Productivity, SSI: stands for Stress Susceptibility Index, and YI: stands for Yield Index. YSI: stands for Yield Stability Index. SII: is for Stress Intensity Index, and HM: stands for Harmonic Mean.

4.9.3 Correlations between drought tolerance indicators and root yield

The positive and significant correlation between Yp and Ys suggests that drought-stressed plants can be selected indirectly based on their performance under non-stressed conditions. The variables STI (r = 0.95), GMP (r = 0.96), MP (r = 0.63), YI (r = 1.00), YSI (r = 0.99) and TOL (r = 0.57) were all significantly and positively related to mean storage root yield under stress (Ys). However, there was a significant and negative correlation between SSI (r = -0.79), HM (r = -0.79), and Ys (r = -0.79) (Table 4.9.3). STI (r = 0.88), GMP (r = 0.92), YI (r = 0.77), SII (r = 0.83), and TOL (r = 0.96) all demonstrated a positive significant relationship with mean stored root yield under stress (Yp). However, there was a negative correlation between SSI (r = -0.26), HM (r = -0.26), and Yp (r = -0.26) (Table 4.17).

Table 4.17 Correlation coefficients between storage root yields and drought tolerance indices

	Yp	Ys	STI	TOL	MP	GMP	SSI	YI	YSI	HM	SII
Yp	1										
Ys	0.77^{**}	1									
STI	0.88^{**}	0.95^{**}	1								
TOL	0.96^{**}	0.57^{*}	0.73^{**}	1							
MP	0.54	0.63^{*}	0.59^{*}	0.42	1						
GMP	0.92^{**}	0.96^{**}	0.97^{**}	0.77^{**}	0.63^{*}	1					
SSI	-0.26	-0.79^{**}	-0.56^{*}	0.01	-0.44	-0.61^{*}	1				
YI	0.77^{**}	1.00^{**}	0.95^{**}	0.57^{*}	0.63^{*}	0.96^{**}	-0.79^{**}	1			
YSI	0.26	0.79^{**}	0.56^{*}	-0.01	0.44	0.61^{*}	-1.00^{**}	0.79^{**}	1		
HM	-0.26	-0.79^{**}	-0.56^{*}	0.01	-0.44	-0.61^{*}	1.00^{**}	-0.79^{**}	-1.00^{**}	1	
SII	0.83^{**}	0.99^{**}	0.96^{**}	0.64^{*}	0.64^{*}	0.98^{**}	-0.73^{**}	0.99^{**}	0.73^{**}	-0.73^{**}	

**, * = significant at 0.01 and 0.05 respectively, NS = non-significant,

Yp: Yield when the irrigation system is fully operational. Ys: Yield under stress, Ȳs: yield mean under stress, Ȳp: yield under non-stress conditions, STI: stands for Stress Tolerance Index. TOL: Tolerance, MPI: is for Mean Productivity Index, GMP: stands for Geometric Mean Productivity, SSI: stands for Stress Susceptibility Index, and YI: stands for Yield Index. YSI: stands for Yield Stability Index. SII: is for Stress Intensity Index, and HM: stands for Harmonic Mean.

4.9.4 Principal components analysis

The principal components (PC) of storage yield under water-stressed and well-watered conditions, as well as drought tolerance indices for the OFSP genotypes, are shown in Table 4.18. In order to find superior genotypes in both situations, the PC analysis was employed to examine the correlations between all variables. The table represents the results of Principal Component Analysis (PCA) for drought tolerance indices. PCA is a statistical technique used to reduce the complexity of large datasets by identifying patterns in the data and reducing the number of variables while retaining the maximum amount of information. In this table, the first and second components are shown, along with their corresponding eigenvalues, the percentage of variance they account for, and the cumulative percentage.

The results showed that the first component has an eigenvalue of 10.522 and accounts for 75.15% of the total variance in the data (Table 4.18). The second component has an eigenvalue of 2.768 and accounts for 19.77% of the variance. The cumulative percentage of the two components is 94.92%, indicating that the majority of the variation in the data can be explained by these two components.

The loadings of each variable on the first and second components are also shown in the table. Loadings represent the correlation between the original variables and the principal components. In this table, we can see that the variables Yp, Ys, STI, MP, GMP, YI, YSI, and HM all have high loadings on the first component, indicating that they are strongly related to each other and contribute significantly to the variation explained by the first component. The variable TOL has a high loading on the second component, indicating that it is strongly related to the second component and contributes significantly to the variation explained by the second component.

Overall, the PCA results suggest that the variables Yp, Ys, STI, MP, GMP, YI, YSI, and HM are strongly related to each other and may be useful in predicting drought tolerance. The variable TOL is less strongly related to the other variables but may still be useful in predicting drought tolerance in combination with the other variables.

Table 4.18 Principal components analysis for drought tolerance indices

Drought tolerance indices	**Components**	
	1	**2**
Yp	0.755	0.643
Ys	0.997	0.037
STI	0.924	0.309
TOL	0.546	0.818
MP	0.659	0.134
GMP	0.951	0.303
SSI	-0.815	0.573
YI	0.997	0.037
YSI	0.815	-0.573
HM	0.990	0.125
SII	-0.815	0.573
Eigen value	10.522	2.768
Percent of variance	75.15%	19.77%
Cumulative percentage	75.15%	94.92%

4.9.5 Cluster analysis

The genotypes were classified into two cluster groups based on storage root yield under stressed and non-stressed environments, as well as drought tolerance indicators (Figure 4.9.1). Clustering indices were used to verify the accuracy of results based on their

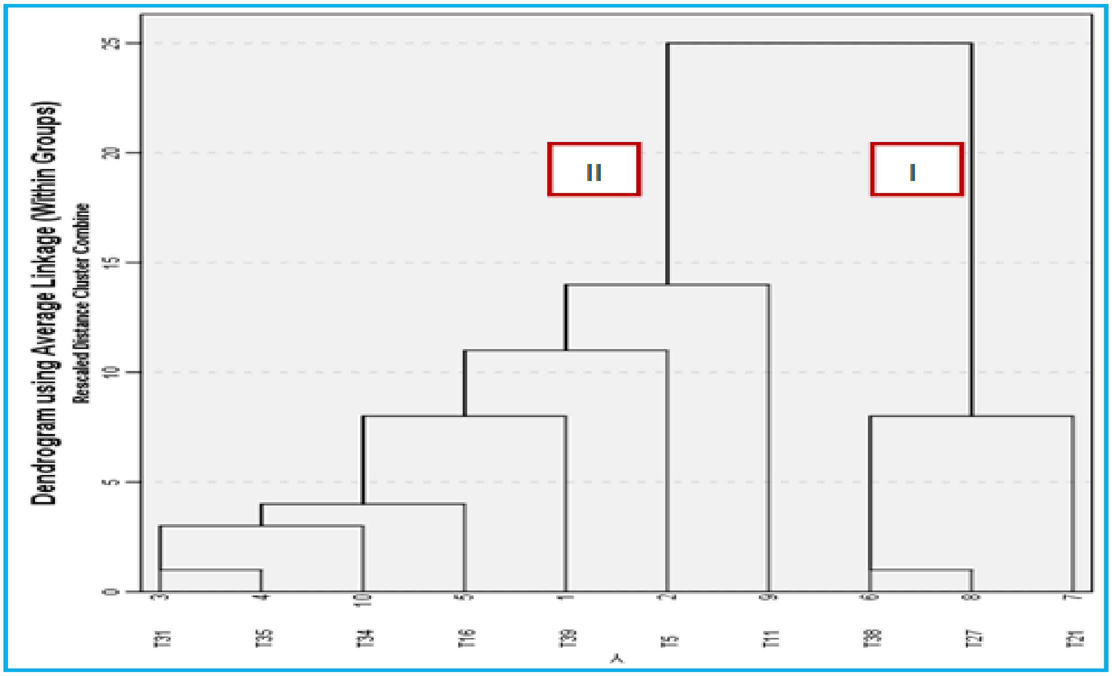

Figure 4.2 UPGMA dendrogram of 10 varieties based on Euclidean distance coefficient and mean yield under non-stress and stress environments, as well as 9 drought tolerance indexes.

Similarity using the average linkage approach. Clusters I and II contained 75.15 percent and 19.77 % of the genotypes, respectively. The first cluster (C1, n = 3) contained the fewest genotypes and was characterized by higher yield during full irrigation and poorer yield when water was scarce. The mean MP, GMP, STI, HM, YI, and YSI values were also the greatest in this cluster, while the SSI and TOL values were the lowest. The genotypes in the cluster stood out because they performed better overall. This cluster also exceeded the grand mean of all other cluster variables, indicating that genotypes in this cluster were wanted based on yield from both environments and selection indices. The second cluster (C2, n = 7) was classed as lowest to intermediate in mean yield in the two moisture regimes, with intermediate values of GMP, MP, STI, HM, YI, and YSI, as well as interim values of TOL and SSI. Overall performance was ordinary to poor among the genotypes in this cluster.

The result shown that the genotypes were classified in to two cluster groups cluster I and cluster II. Cluster I contained the fewest genotypes (n=3) and was characterized by higher yield during full irrigation and poorer yield when water was scarce. The genotypes in this cluster also had the greatest mean values for MP, GMP, STI, HM, YI, and YSI, indicating that they performed better overall. Additionally, the genotypes in this cluster had the lowest values of SSI and TOL, which are indicators of drought susceptibility.

On the other hand, Cluster II contained seven genotypes and had the lowest to intermediate mean yield in both moisture regimes. The genotypes in this cluster had intermediate values of GMP, MP, STI, HM, YI, and YSI, as well as intermediate values of TOL and SSI. Overall, the performance of the genotypes in this cluster was ordinary to poor.

The result indicates that the genotypes in Cluster I are desirable for cultivation under both stressed and non-stressed environments, as they had the highest overall performance and were the most drought-tolerant. The genotypes in Cluster II, on the other hand, had lower overall performance and were less drought-tolerant. This information can be useful for breeders and farmers in selecting and cultivating the most suitable genotypes for different environments and stress conditions.

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The findings of the study were summarized according to the statement of the problem stated in chapter 1.

There has been little research on the morphological characteristics of sweet potato types suited for human use as well as for livestock feed. The bulk of morphological characteristics varied significantly across the types studied in this study. The morphological characteristics that were assessed among the varieties were vine characters, leaf characters, and storage root characters. ANOVA was applied to 15 descriptors, and almost all morphological descriptors showed significant differences. Table 4.5 shows the results of a basic liner correlation study of root yield, growth, and yield characteristics in sweet potato. Storage root yields/SYld were shown to have significant relationships with VID (r = 0.258), MLS (r = 0.364), PL (r = 0.257), EGC (r = 0.297), LLN (r = 0.261), and VTP (r = 0.218). Primary component analyses 1 and 2 were the most major contributors to variation among genotypes, according to PCA data. The key characteristics that contributed to this variation were vine Internodes length (VIL), vine internodes diameter (VID), leaf lobe number (LLN), central leaf lobe (CLL), vine Tip Pubescence (VTP), vine growth rate (VGR), mature Leaf size (MLS), petiole Length (PL), root peel colour (RPC), and root flesh colour (RFC). The results of the cluster analysis revealed that the genotypes in the super cluster A group shown strong shared comparable traits, and based on their mean results, they demonstrated from medium to highest score in most traits and were grouped together. Furthermore, the genotypes in this group qualified for dual-purpose properties.

Ethiopian farmers' efforts to maximise crop yield are hampered by a lack of land, capital, and other biotic and abiotic factors (Taffese *et al.,* 2011; Bakabil, 2014). This poses a significant threat to Ethiopia's food security. One answer to this challenge is to create dual-purpose sweet potato cultivars capable of producing considerable amounts of stored root and above-ground biomass. This study discovered 30 genotypes out of 40 that qualified for dual-purpose using the Leon-velarde classification approach. Varieties with ratings in the 0.2-0.3 range are classified as dual-purpose high forage genotypes. A dual-purpose high root variety, on the other hand, has a value range of 0.3-0.55.30 cultivars were identified as dual-purpose morphologically as a consequence of the root/vine ratio. There are nine dual-purpose high forage types and twenty-one dual-purpose high root varieties.

Despite the fact that drought is the most serious threat to OFSP production, progress in developing drought-resistant genotypes is limited by a lack of appropriate selection criteria. As a result, developing this crop to make it more drought resistant is a critical step towards satisfying national food demands. The study found a highly significant difference (P 0.001) in the performance of all genotypes for the following drought screening variables: number of branches (NB), vine fresh weight (VFW), vine internode length (VIL), and leaf area (LA) for all traits except yield. The traits vine length (VL) and vine internode diameter (VID) also showed a significant difference (P 0.001). Different indices define different genotypes as drought resistant; thus, searching for drought tolerant genotypes using a single criterion yields varied results. To select promising drought tolerant genotypes, the mean rank, standard deviation of ranks, and rank sum of all indices were calculated. MUSG014065-21-13 (3.3), MUSG014065-21-14

(4.6), and MUSG014019-7-50 (5.1) had the best mean rank, rank sum, and relatively low rank sum and standard deviation of ranks when all indices were examined. Drought-resistant genotypes included MUSG014001-3-11 (11.4), CN1448-49-28-8 (10.0), MUSG014052-51-35 (8.4), and Naspot-12 (8.1), while drought-sensitive genotypes included MUSG014001-3-11 (11.4), CN1448-49-28-8 (10.0), MUSG014052-51-35 (8.4), and Naspot-12 (8.1). According to the PCA results, the variables Yp, Ys, STI, MP, GMP, YI, YSI, and HM are strongly connected and may be useful in predicting drought tolerance.

5.2 Conclusions

In the study for morphological characterization, phenotypic variability observed among the 40 genotypes for leaf, vine and root parameters except for central leaf lobe (CLL), Petiole length (PL), and root thickness (RT).The study on morphological variables revealed the existence of two super clusters, A and B. Super cluster A consisted of only six genotypes, which shared many traits and demonstrated better performance on the variables tested. In contrast, super cluster B contained 20 genotypes that showed medium performance on the same variables. The PCA analysis identified six variables, namely PT, VGR, VIL, VID, MLS, and TW, which had a significant correlation with the first principal components and contributed the most to the observed variation among the 40 genotypes. This finding indicates that these variables are crucial for the characterization of genotypes. Overall, the study suggests that the six genotypes in super cluster A are highly similar and may be of great interest for future research and breeding programs.

The research finding showed that 30 genotypes out of 40 qualified for dual-purpose based on their index value of root to vine ratio (R/V). In the drought tolerance evaluation study, the genotypes evaluated in the study varied significantly in terms of their response to drought stress, with some genotypes exhibiting greater tolerance to drought than others. The study also revealed that the genotypes MUSG014065-21-13, MUSG014065-21-14 and MUSG014019-7-50 had the lowest rank sum (RS) and standard deviation of rank sum (RSD) and considered as a drought tolerant genotypes.

There was a significant difference in both vegetative and root yield traits under extreme water stress as the mean value decreased. The drought tolerance of 10 OFSP genotypes was assessed in the study, and the results showed that three genotypes, namely (MUSG014065-21-13), (MUSG014065-21-14), and (MUSG014019-7-50), exhibited excellent performance under both moderate and extreme water stress conditions. Based on these findings, the study concludes that these three genotypes have promising potential for use in future breeding programs aimed at developing drought-tolerant sweet potato crops.

In examining drought selection indices, Stress tolerance index (STI), geometric mean productivity (GMP), yield index (YI), stress intensity index (SII) and tolerance (TOL) indices were shown to be the best in identifying drought tolerant genotypes based on their strong correlation with yield under stress conditions as well as it were found to be the most effective indicators of drought tolerance, as they provided the highest discrimination between genotypes. The genotypes were classified into two clusters based on their storage root yield under stressed and non-stressed environments, as well as their drought tolerance indices. The first cluster contained genotypes with higher yield during full irrigation and poorer yield under drought stress, but they had better overall performance, as indicated by their higher values for MP, GMP, STI, HM, YI, and YSI. The second cluster contained genotypes with lower to intermediate yields in both moisture regimes, and their overall performance was ordinary to poor. The study highlights the importance of identifying and selecting genotypes with improved drought tolerance, as this can have significant implications for improving crop productivity under water-limited conditions. The results suggest that selecting genotypes based on their Stress tolerance index (STI), geometric mean productivity (GMP), yield index (YI), stress intensity index (SII) and tolerance (TOL) values could be an effective approach for improving drought tolerance in sweet potato breeding programs. This study's findings will be immensely useful in planning future sweet potato breeding initiatives, especially in Ethiopia.

In summary, the study's findings have practical implications for small farmers in Ethiopia. The information can be used to identify and select sweet potato genotypes with improved drought tolerance and optimal dual-purpose traits for future breeding programs. This can ultimately enhance crop productivity, food security, and income generation opportunities for small-scale farmers in water-limited regions.

5.2 Recommendations

Based on the research findings on morphological characterization and drought tolerance evaluation of sweet potato genotypes, it is recommended to focus on identifying and selecting genotypes with improved drought tolerance for breeding programs. This can be done by using indicators such as the Stress tolerance index (STI), geometric mean productivity (GMP), yield index (YI), stress intensity index (SII), and tolerance (TOL) values to screen and select the most drought-tolerant genotypes.

Based on the finding that 30 out of 40 genotypes qualified as dual-purpose based on their root to vine ratio (R/V) index value, it is recommended that further research should focus on the cultivation and evaluation of these dual-purpose genotypes under different environmental conditions to assess their performance and potential for use in both food and feed production systems. Additionally, efforts should be made to promote the adoption of these dual-purpose sweet potato genotypes among farmers to enhance the economic and nutritional benefits of sweet potato cultivation.

Further research could also be conducted to identify the molecular markers associated with drought tolerance in sweet potato genotypes to facilitate marker-assisted selection (MAS) in breeding programs. In addition, it is recommended to conduct field trials to evaluate the performance of the selected genotypes under various environmental conditions to ensure their stability and suitability for cultivation in different regions.

Moreover, collaboration between researchers, farmers, and policymakers is essential to promote the adoption of drought-tolerant sweet potato varieties and support sustainable agricultural practices that can enhance food security and alleviate poverty in water-limited areas.

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APPENDICES

Appendix I: Analysis of variance (ANOVA) results morphological variations among sweet potato genotypes

	Sources of variation	df	Sum of Squares	Mean Square	F stat	P value
Yield per ton/ha	Replication					
	Treatments/genotype	**39**	957.16	24.5427	59.097	2.2e-16 ***
	Residual error	**25**	10.38	0.4153		
	Replication					
Plant type	Treatments/genotype	**39**	168313	4315.7	16.278	1.527e-10 ***
	Residual error	**25**	6628	265.1		
	Replication					
Vine growth rate	Treatments/genotype	**39**	153276	3930.1	14.174	7.304e-10 ***
	Residual error	**25**	6932	277.3		
	Replication					
Vine internodes length	Treatments/genotype	**39**	195.096	5.0025	4.6801	6.403e-05 ***
	Residual error	**25**	26.722	1.0689		

	Sources of variation	**df**	**Sum of Squares**	**Mean Square**	**F stat**	**P value**
	Replication					
Vine internodes diameter	Treatments/genotype	**39**	279.630	7.1700	13.154	1.682e-09 ***
	Residual error	**25**	13.627	0.5451		
Mature Leaf Size	Replication					
	Treatments/genotype	**39**	159.703	4.0950	5.3941	1.736e-05 ***
	Residual error	**25**	18.979	0.7591		
	Replication					
Petiole Length	Treatments/genotype	**39**	116.632	2.9906	1.0063	0.5037
	Residual error	**25**	74.297	2.9719		
	Replication					
Estimated ground rate	Treatments/genotype	214.75	5.5064	2.1594	0.02262 *	
	Residual error	63.75	2.5500			
	Replication					
Storage cortex root thickness	Treatments/genotype	39	98.585	2.5278	0.8022	0.737
	Residual error	25	78.773	3.1509		
Shape of Central leaf lobe	Replication					
	Treatments/genotype	39	293.24	7.5190	1.0232	0.4855
	Residual error	25	183.71	7.3482		
	Replication					
Vine pigmentation	Treatments/genotype	39	347.20	8.9026	178.05	2.2e-16 ***
	Residual error	25	1.25	0.0500		

	Replication					
Root shape	Treatments/genotype	39	300.609	7.7079	2.3418	.01373 *
	Residual error	25	82.285	3.2914		
	Replication					
Leaf lobe number	Treatments/genotype	39	212.00	5.436	2.456e+29	<2e-16 ***
	Residual error	25	0.00	0.000		
	Replication					
Twining	Treatments/genotype	39	270.86	6.945	2.030	0.0324 *
	Residual error	25	85.52	3.421		
	Replication					
Vine tip pubescence	Treatments/genotype	39	20.0	0.5128	1.597e+30	2e-16 ***
	Residual error	25	0.0	0.0000		
	Replication					
Vein leaf pigmentation	Treatments/genotype	39	78.8	2.021	2.859e+29	<2e-16 ***
	Residual error	25	0.0	0.000		
	Replication					
Root peel color	Treatments/genotype	39	363.6	9.323	5.143e+29	2e-16 ***
	Residual error	25	0.0	0.000		
	Replication					
Root flesh color	Treatments/genotype	39	274.00	7.026	5.688e+28	<2e-16 ***
	Residual error	25	0.00			

Level of significance ns, *, **, * denoting non- significant, significant and highly significant at $p < 0.05$ and at $p < 0.001$.**

SYLD: Yield ton^{-ha}; VID: Vine internode diameter; EGC: Estimated ground covers
VIP: vine pigmentation
PT: Plant type; MLS: Mature leaf size LLN: Leaf lobe number
VTP: Vine tip pubescence
VIL: Vine internodes length PL: Petiole length TW: Twining ability
LVP: Leaf vein pigmentation
SCLL: Shape of Central leaf lobe RFC: Root flesh color RS: Root shape
SRCT: Storage root cortex thickness
RPC: Root peel color VGR: Vine growth rat

Appendix II: A key published article of this thesis

Article 1

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Research Article · Open Access · Peer-Reviewed

Phenotypic characterization of sweet potato (*Ipomoea batatas L.*) genotypes in Ethiopia for selection of those possessing optimal dual-purpose

Selamawit Abebe Gitore[1]*, Benjamin Danga[2], Sylvia Henga[2] and Fekadu Gurmu[3]

+ Author and article information

[1]Department of Dry land Agriculture, Faculty of Agricultural Science and Technology, Kenyatta University, Nairobi, Kenya
[2]Faculty of Agricultural Science and Technology, Kenyatta University, Nairobi, Kenya
[3]Southern Agricultural Research Center, Hawassa, Ethiopia

***Corresponding author:**Selamawit Abebe Gitore, MSc, Department of Dry land Agriculture, Faculty of Agricultural Science and Technology, Kenyatta University, Nairobi, Kenya, Tel: +254702601280; E-mail: abate4fam@gmail.com

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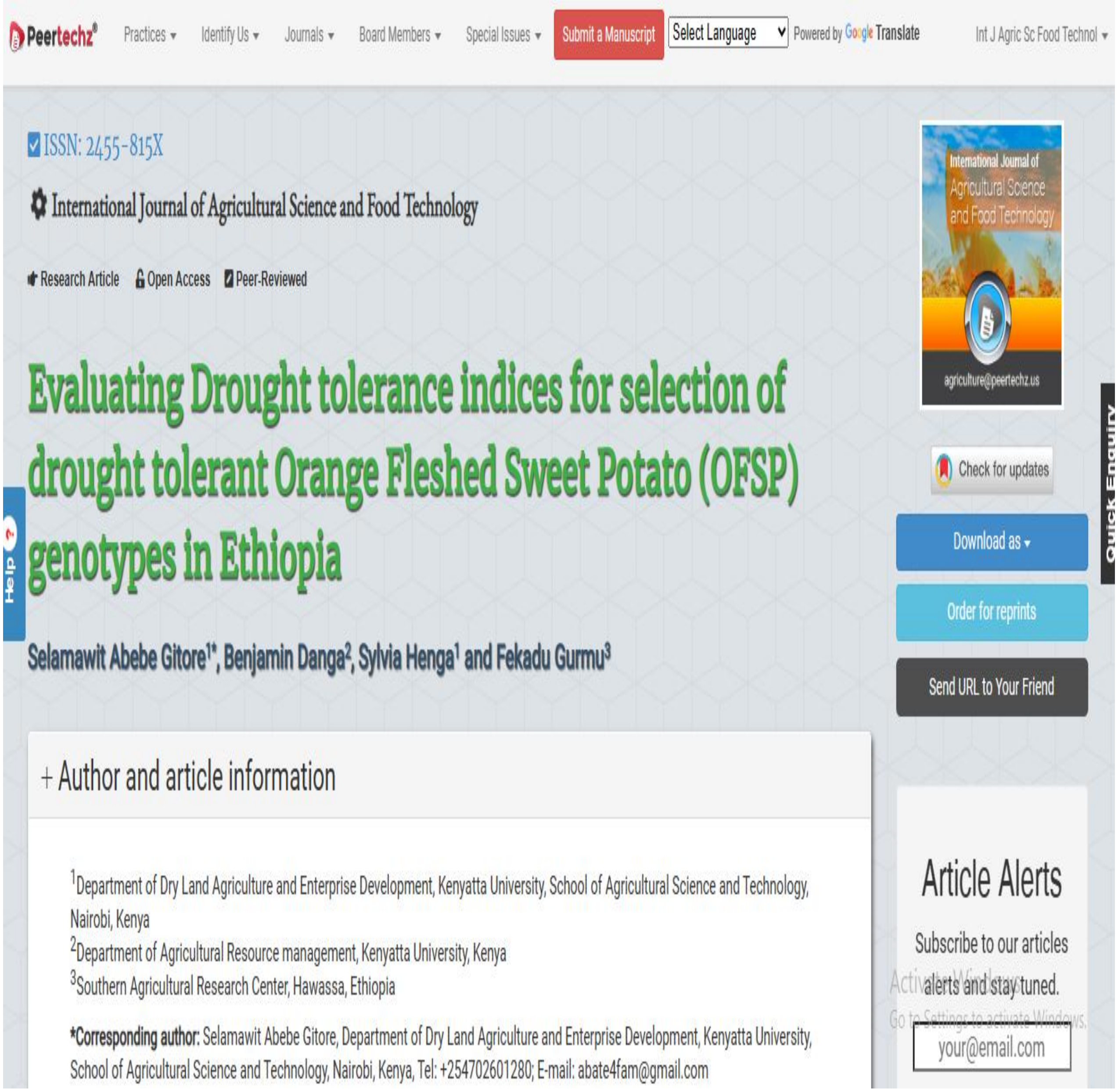
Article 2



ISSN: 2455-815X

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Research Article Open Access Peer-Reviewed

Evaluating Drought tolerance indices for selection of drought tolerant Orange Fleshed Sweet Potato (OFSP) genotypes in Ethiopia

Selamawit Abebe Gitore[1]*, Benjamin Danga[2], Sylvia Henga[1] and Fekadu Gurmu[3]

+ Author and article information

[1]Department of Dry Land Agriculture and Enterprise Development, Kenyatta University, School of Agricultural Science and Technology, Nairobi, Kenya
[2]Department of Agricultural Resource management, Kenyatta University, Kenya
[3]Southern Agricultural Research Center, Hawassa, Ethiopia

***Corresponding author:** Selamawit Abebe Gitore, Department of Dry Land Agriculture and Enterprise Development, Kenyatta University, School of Agricultural Science and Technology, Nairobi, Kenya, Tel: +254702601280; E-mail: abate4fam@gmail.com

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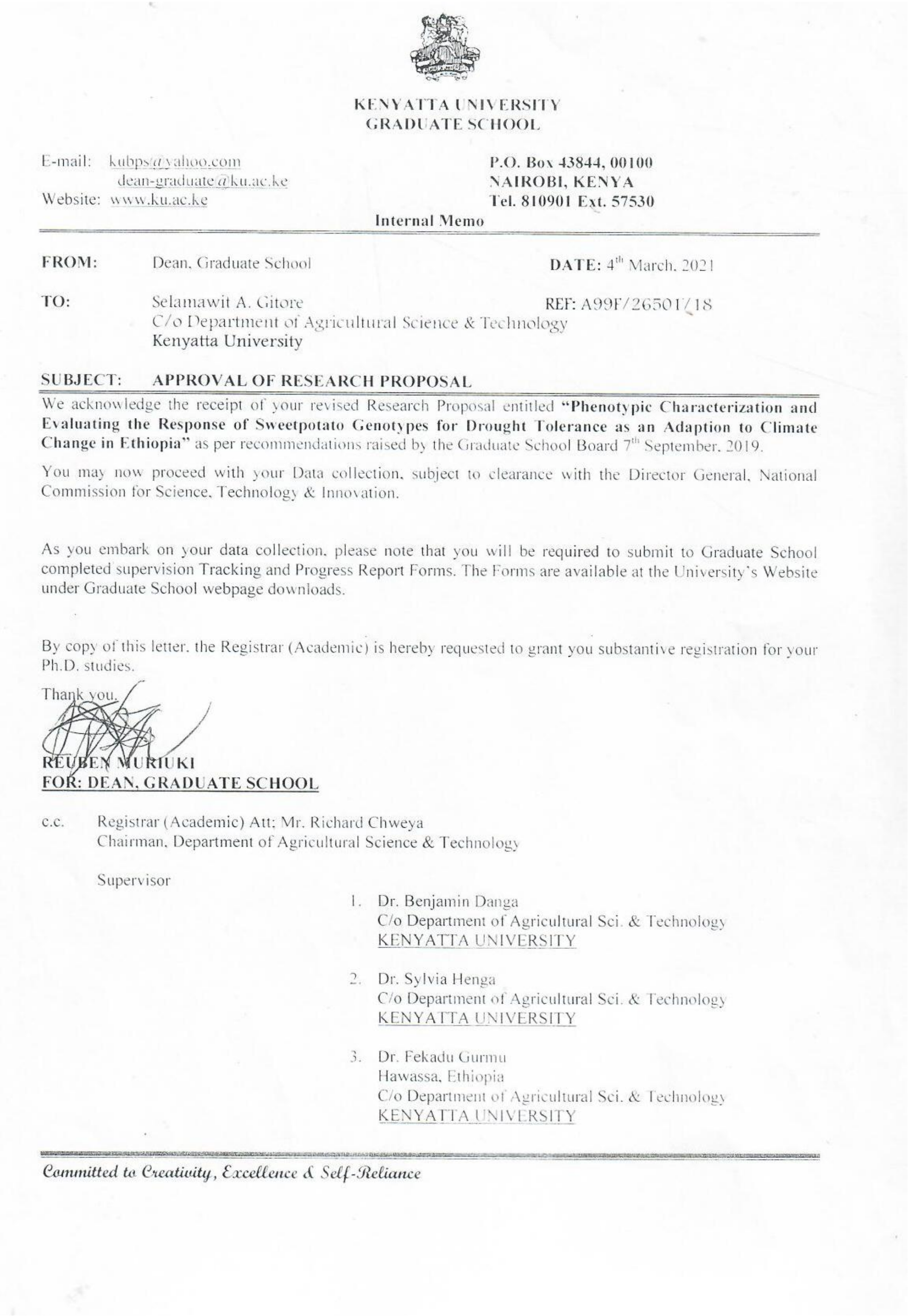
Appendix III: Approval of Research Proposal



KENYATTA UNIVERSITY
GRADUATE SCHOOL

E-mail: kubps@yahoo.com
dean-graduate@ku.ac.ke
Website: www.ku.ac.ke

P.O. Box 43844, 00100
NAIROBI, KENYA
Tel. 810901 Ext. 57530

Internal Memo

FROM: Dean, Graduate School **DATE:** 4th March, 2021

TO: Selamawit A. Gitore **REF:** A99F/26501/18
C/o Department of Agricultural Science & Technology
Kenyatta University

SUBJECT: APPROVAL OF RESEARCH PROPOSAL

We acknowledge the receipt of your revised Research Proposal entitled **"Phenotypic Characterization and Evaluating the Response of Sweetpotato Genotypes for Drought Tolerance as an Adaption to Climate Change in Ethiopia"** as per recommendations raised by the Graduate School Board 7th September, 2019.

You may now proceed with your Data collection, subject to clearance with the Director General, National Commission for Science, Technology & Innovation.

As you embark on your data collection, please note that you will be required to submit to Graduate School completed supervision Tracking and Progress Report Forms. The Forms are available at the University's Website under Graduate School webpage downloads.

By copy of this letter, the Registrar (Academic) is hereby requested to grant you substantive registration for your Ph.D. studies.

Thank you.

REUBEN MURIUKI
FOR: DEAN, GRADUATE SCHOOL

c.c. Registrar (Academic) Att: Mr. Richard Chweya
Chairman, Department of Agricultural Science & Technology

Supervisor

1. Dr. Benjamin Danga
   C/o Department of Agricultural Sci. & Technology
   KENYATTA UNIVERSITY
2. Dr. Sylvia Henga
   C/o Department of Agricultural Sci. & Technology
   KENYATTA UNIVERSITY
3. Dr. Fekadu Gurmu
   Hawassa, Ethiopia
   C/o Department of Agricultural Sci. & Technology
   KENYATTA UNIVERSITY

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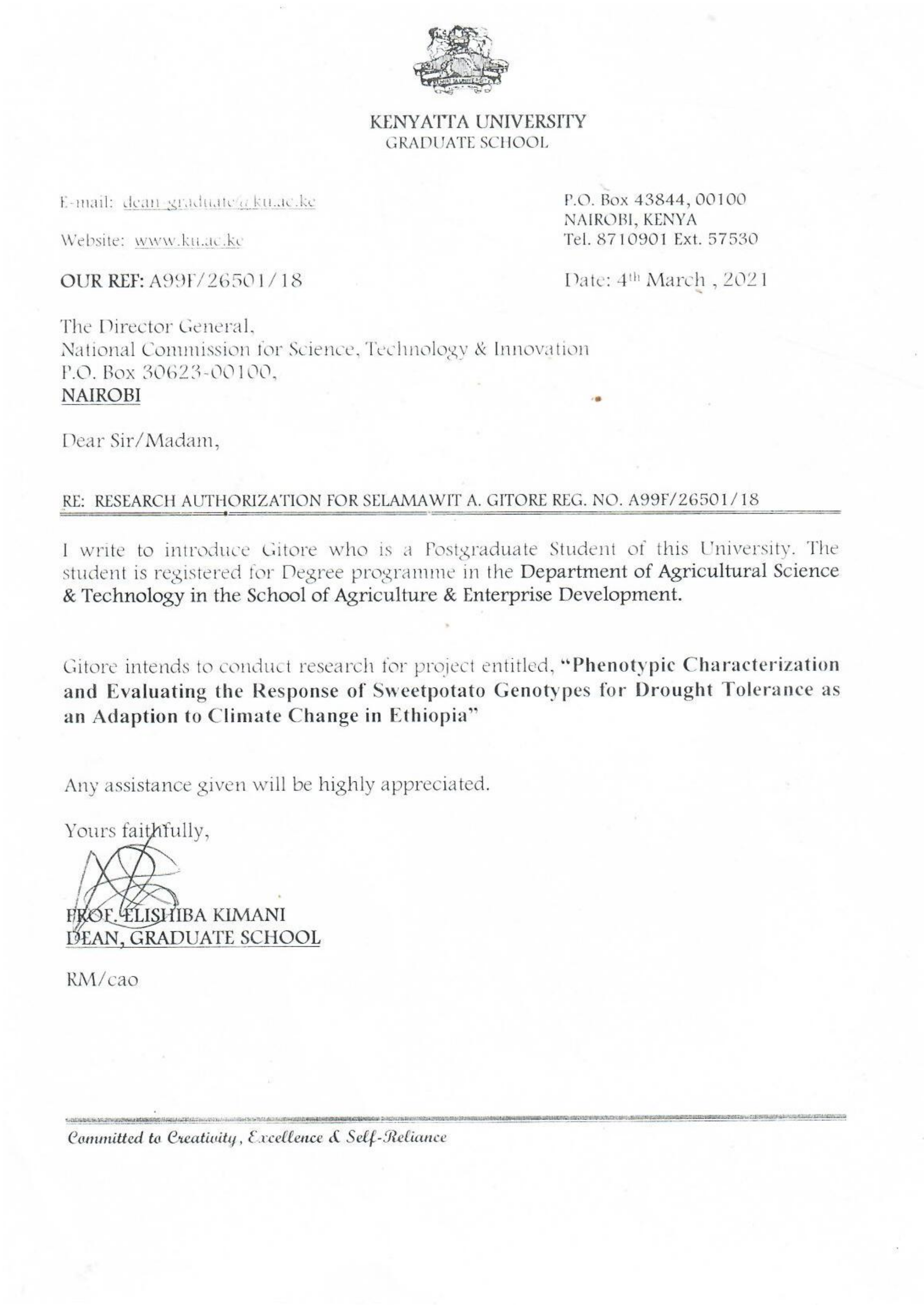
Appendix IV: Authorization of Research Proposal



KENYATTA UNIVERSITY
GRADUATE SCHOOL

E-mail: dean-graduate@ku.ac.ke
Website: www.ku.ac.ke

P.O. Box 43844, 00100
NAIROBI, KENYA
Tel. 8710901 Ext. 57530

OUR REF: A99F/26501/18

Date: 4th March , 2021

The Director General,
National Commission for Science, Technology & Innovation
P.O. Box 30623-00100,
NAIROBI

Dear Sir/Madam,

RE: RESEARCH AUTHORIZATION FOR SELAMAWIT A. GITORE REG. NO. A99F/26501/18

I write to introduce Gitore who is a Postgraduate Student of this University. The student is registered for Degree programme in the **Department of Agricultural Science & Technology in the School of Agriculture & Enterprise Development.**

Gitore intends to conduct research for project entitled, **"Phenotypic Characterization and Evaluating the Response of Sweetpotato Genotypes for Drought Tolerance as an Adaption to Climate Change in Ethiopia"**

Any assistance given will be highly appreciated.

Yours faithfully,

PROF. ELISHIBA KIMANI
DEAN, GRADUATE SCHOOL

RM/cao

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Appendix V: Research Permit

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Hawassa University
College Of Agriculture
Human Resource Service

Ref No:- ACA /45/ 730
Date:--- 06/08/2019

Dear Sir/Madam

SUBJECT: PERMISSION GRANTED FOR RESEARCH AT HAWASSA AGRICULTURE COLLEGE

This Letter serves to confirm that we have approved Selamawit Abebe Gitore's request to carry out her doctorial research in our field of study.

Hawassa Agriculture College will provide her with the access to the designated research field and any necessary resources required for the successful completion of their study. We are confident that she will handle these resources responsibly and ensure their proper care throughout the research process.

Sincerely yours

Gc. et I. gara
Human Resource
Management Team Leader

+251-046-220-16-71
+251-046-220-45-72
Fax: +251-046-220-67-11
P.O.BOX: 05 Hawassa