EVALUATING THE POST-FLOODING RECOVERY POTENTIAL AND GROWTH RESPONSE OF DIFFERENT SOLANUM AETHIOPICUM (SHUM) GENOTYPES

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ABSTRACT

The increasing occurrence of flooding events due to climate change poses a serious threat to crop production in sub-Saharan Africa, where *Solanum aethiopicum* Shum serves as an important leafy vegetable for food, nutritional and income security. This study evaluated the post-flooding recovery potential and growth responses of three *Solanum aethiopicum* Shum genotypes E11, E15, and E16 under controlled flooding conditions at Uganda Christian University. A randomized split plot design was used, subjecting plants to two weeks of partial submergence followed by recovery monitoring for a period of 14days. Results revealed significant genotypic variations in recovery time and, survival rates as measured using physiological parameters (such as chlorophyll content), and morphological traits (including leaf area, root length, and biomass accumulation). Genotype E11 exhibited the fastest recovery and highest survival rate (99.17%), while E16 demonstrated superior biomass production and root development. Analysis of the physiological traits showed that E15 and E16 maintained higher chlorophyll content during the recovery phase, indicating efficient restoration of photosynthetic capacity. Morphological recovery strategies differed, with E11 focusing on fewer but larger leaves, and E15 and E16 were favouring new leaf proliferation. These findings highlight the genetic diversity in flooding tolerance among *Solanum aethiopicum* Shum genotypes and underscore the potential for breeding flood-resilient cultivars to ensure food security in flood-prone regions.

Key words:

Solanum aethiopicum Shum, Flooding stress, Post-flooding recovery, potential genetic diversity, Morphological response, Physiological response, Flood tolerance breeding

DECLARATION

I, Mukisa Tonny hereby declare that this is my original work, and it’s not plagiarised and has not been submitted to any other institution for any award.

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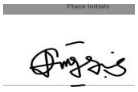
Signature: 

Date: 27th APRIL 2025

APPROVAL

This report has been submitted with the approval of the persons below as a requirement for the award of a bachelor of agricultural science and entrepreneurship

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DEDICATION

I dedicate this research dissertation to all the different individuals that stood by me during the entire research journey. This includes my parents who provided financial support, my classmate who extended a helping hand, my supervisor Madam PAMELA NAHAMYA KABOD who offered wisdom and assistance.

I also dedicate it to the Faculty of Agricultural Sciences to all teaching and non-teaching stuff who shaped my research journey till the end.

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LIST OF ACRONYMS AND ABBREVIATIONS

PCD .... programmed cell death

NPQ......... non-photochemical quenching

NPK........... nitrogen phosphorous potassium

SE............... standard error

LSD................ lowest significant difference

SD ...... standard deviation

CV..... coefficient of variance

CHAPTER ONE: INTRODUCTION

1.1 Back ground

Solanum aethiopicum Shum also known as African eggplant, *Solanum aethiopicum (*shum*)*, is a deciduous shrub in the family Solanaceae which is grown for its edible leaves that are cooked and eaten as vegetables. This species is believed to have originated from Africa and was domesticated from the wild *Solanum anguivi Lam*. (Anaso, 1991). African eggplant is a highly branching plant which can grow up to 2 m (6.6 ft.) in height. It's a short plant with small, smooth leaves. Its shoots are edible, but its small fruits are bitter and less preferred. The leaves of the plant are arranged alternately on the stems and have smooth or lobed margins. Leaf blades may reach up to 30 cm (11.8 in) in length and 21 cm (8.3 in) in width. The leaf petioles are oval or elliptical in shape, reaching up to 11 cm (4.3 in) in length. (Regine Tchientche Kamga *et al.,* 2015). Plants produce clusters of up to 12 white flowers which develop into egg or spindle-shaped berries which are red to orange in colour with a smooth or grooved surface depending on variety. (Adeniji *et al.,* 2019). African eggplant may also be referred to as scarlet eggplant, bitter tomato, mock tomato, garden egg or Ethiopian.

Solanum aethiopicum Shum grows well in well drained deep soils and a pH of around 5.5-6.8. *Solanum aethiopicum* Shum also requires conditions that are warm and humid in order to thrive well. When planting Shum, for better performance in terms of yields, seeds are first planted in a nursery bed 15cm apart and 20cm with in rows (Aguessy *et al.,* 2021). The seedlings are then transplanted to main garden when they reach 15cm-20cm in height. Shum benefits from frequent irrigation in the dry season particularly when fruiting. Young leaves of *Solanum aethiopicum* Shum can be harvested for 45-60 days of growth Shum. (G. Sseremba, 2019). *Solanum aethiopicum* Shum is known for its nutritional value and income-generating potential for farmers. The crop is rich in both macro- and micro-nutrient compared with other vegetables and is suitable for ensuring food and nutritional security. (Kamga, R.T). It also possesses several medicinal properties and is currently employed in the treatment of high blood pressure, diabetes, cholera, urinary complications as well as skin infections in humans. (Han et al., 2021). All these advantages show that *Solanum aethiopicum* Shum is an important crop in as far as food security is concerned in many parts of the country especially in local communities. Research shows that over four million individual in Uganda deal in the production, trade and consumption of *Solanum aethiopicum* Shum making it of economic importance to the economy of Uganda (Nakyewa *et al.,* 2021). However, since *Solanum aethiopicum* Shum is cultivated mostly in wetlands since it's a leafy vegetable and it requires enough water for leaf establishment, its production is threatened by prolonged flooding since wet lands are prone to flooding. This is due to climate change, poor drainage and many other human activities that disrupt the water movement and drainage hence causing floods.

Flooding is an environmental stress that hinders crop growth and productivity severely especially in regions of Uganda that are prone to flooding due to extreme weather changes or climate change. Floods were the second gravest agricultural disaster, next to droughts, as they were responsible for $21B in crop and livestock loss from 2008 to 2018 in the developing world (FAO 2021). Flooding refers to an overflow of water onto normally dry land, which is mainly caused by heavy rainfall and river overflow. It can occur suddenly (flash flooding) or gradually (river flooding) and typically involves significant amounts of water covering an area (Mohammad *et al.,* 2022). Flooding in plants (agriculture) can be classified in two different for categories depending on the depth of water. The two categories of flooding include water-logging and submergence. Water-logging refers to a condition where water exists on the surface and only plant roots are surrounded by water. On the other hand submergence is a condition where the whole plant is partially or completely covered by water (Tian *et al.,* 2020). Flooding causes negative effects on the physiological, vegetative growth of vegetables. One of the symptoms of the damage caused by flooding is yellowing and death of leaves. (Gibbs and Greenway, 2003). The early death of leaves and retarded growth of shoots is as a result of the inhibition of nitrogen up take by the plant which eventually leads to leaf chlorosis. Leaf chlorosis which is as a result of Nitrogen deficiency implies that plants are not able to make their own food leading to destruction of the plant Hence a posing a threat to food security (Ezin *et al.,* 2010). Plant failure to take up nutrients from the soil is due to oxygen deficiency caused by floods. Flooding restricts oxygen availability which is important for cellular respiration; the in availability of oxygen around the root zone causes anaerobic conditions that lead to shrinking of plant roots which makes it difficult for them to take up nutrients and water for the plant. Anaerobic conditions produced due to lack of oxygen, produces toxic by-products for example ethanol and lactate (Muhammad Arslan Ashraf, 2012). These two toxic chemicals accumulate in plant tissues leading to cell damage and death. Oxygen deficiency due to flooding also leads to photosynthesis reduction, stunted growth, oxidative stress and many others (da-Silva & do Amarante, 2020).

However different studies carried on flooding in plants show that some plants have evolved strategies that enable them resist against the period they are subjected to flooding. Some studied show that some plants are able to restrict growth through keeping the minimum energy and carbon consumption for surviving underwater and after the water is removed, these plants recover rapidly. (Zhao *et al.,* 2021). Plants like tomatoes produce new adventitious roots that help them with stand the flooding conditions (Ezin *et al.,* 2010). Different rice cultivators with stand flood periods by restricting shoot elongation as well as carbohydrate consumption, and will be recovered when the flooding period is done.

The study aims to evaluate the recovery responses of different *S. aethiopicum* (shum) genotypes under controlled flooding conditions. Understanding the mechanisms and recovery rates will help identify resilient genotypes suitable for flood-prone regions hence increasing food productions and ensuring food security.

1.2 PROBLEM STATEMENT

Solanum aethiopicum shum, commonly known as African eggplant is a vital leafy vegetable cultivated in sub-Saharan Africa for its nutritional and economic value. It is recognized for its tolerance to various biotic and abiotic stresses, including heat and drought, which makes it a resilient crop in regions facing climate variability (Akoroda *et al.,* 2020). However, recent increases in climate-induced flooding have posed significant challenges to its production, impacting plant physiology, survival, and yield. Flooding, characterized by water logging and oxygen deprivation in the root zone, negatively affects plant growth and metabolism. The magnitude of crop losses due to flooding has spread worldwide, with reports indicating a 10–20% yield loss in key crops throughout the year due to water logging (Voesenek & Bailey-

Serres, 2015). In Africa, unpredictable rainfall patterns and flooding events have reduced agricultural productivity, especially in areas where smallholder farmers rely on flood-sensitive crops like *Solanum aethiopicum shum* (Mwadzingeni *et al.,* 2016). Understanding the recovery mechanisms of crops post-flooding is critical for developing resilient varieties. Efforts have been made to identify and promote stress-tolerant varieties of *Solanum aethiopicum* shum. Breeding programs have mainly focused on enhancing drought resistance (Danquah *et al.,* 2021). However, similar strides in addressing flooding resilience are limited. Agronomic interventions, such as raised beds and drainage systems, have also been employed to mitigate flooding impacts (Kumwenda *et al.,* 2018). However, these solutions remain lacking for unpredictable or prolonged flooding events. Even with the acknowledgment of *Solanum aethiopicum* shum potential as a resilient crop, studies on its post-flooding recovery dynamics remain missing. Important questions regarding the physiological and morphological responses of different genotypes to flooding stress and their subsequent recovery mechanisms remain lacking answers. There is also less data on the role of specific genotype traits in determining post-flooding recovery potential. Understanding the post-flooding recovery potential and growth response of *Solanum aethiopicum* shum genotypes is vital for enhancing food security in flood-prone regions. This research can guide the selection of flood-resilient genotypes, contributing to sustainable agricultural systems. In addition, it will provide understandings into plant adaptation mechanisms under stress, aiding in the development of targeted breeding strategies to improve resilience not only in *Solanum aethiopicum* Shum but also in other crops.

1.3 Purpose of study

The purpose of studying the post-flooding recovery potential and growth response of different *Solanum aethiopicum* (Shum) genotypes is to evaluate their ability to adapt and thrive under stress conditions, particularly flooding. This research helps in understanding the resilience mechanisms of these genotypes, identifying varieties with higher tolerance, and optimizing their cultivation for regions prone to flooding. The findings could support crop improvement programs and enhance agricultural productivity in flood-affected areas (Apolot *et al.,* 2020).

1.4 objectives

1.4.1 Main objective

I. To determine the flood tolerance in *Solanum aethiopicum* Shum for increased crop productivity

1.4.2 Specific objectives

I. To examine the variations in the recovery time among various *Solanum Aethopicum* shum genotypes from flooding stress.
II. To assess the agronomic performance of the recovered genotypes focusing on physiological and morphological changes in response to flood stress.

1.5 Hypotheses

1.5.1 Hypothesis 1

Solanum aethiopicum shum genotypes will exhibit 60-85%recovery rates from flooding stress, with certain genotypes demonstrating superior adaptive traits that allow them recover more effectively compared to others (Colmer & Voesenek, 2009).

1.5.2 Hypothesis 2

Recovered *Solanum aethiopicum* shum genotype from flooding stress will exhibit distinct physiological and morphological changes (G. Sseremba, 2019).

1.6 Scope of study

This research focused on accessing the recovery potential of different *Solanum aethiopicum* shum genotypes from flooding stress, by identifying those that recover faster after a period of flooding. Understanding these responses is crucial for developing resilient cultivars that can withstand adverse conditions. This study will be conducted in a screen house in Uganda Christian University on three different genotypes of *Solanum aethiopicum* Shum which are E11, E15, and E16. Different morphological and physiology parameters for example leaf size, leaf area, chlorophyll content, root length will be measured to access recovery rates and resilience of the three *Solanum aethiopicum* Shum genotypes to floods.

1.8 Justification

Solanum aethiopicum Shum, commonly known as African eggplant or Shum is a widely cultivated indigenous vegetable in sub-Saharan Africa. It is a crucial source of vitamins, minerals, and dietary fibre, contributing significantly to food security and income generation for smallholder farmers. Despite its economic and nutritional importance, studies on its response to abiotic stresses, such as flooding, remain limited. (Abukutsa-Onyango, M. (2010). Flooding adversely affects plant growth by limiting oxygen availability, impairing root functions, and disrupting nutrient uptake. Understanding the recovery mechanisms of *Solanum aethiopicum* Shum genotypes can aid in breeding programs focused on flood-resilient genotypes. This is particularly important in regions where climate change is increasing the frequency and intensity of extreme weather events, like flooding. (Bailey-Serres et al. (2012). This research aligns with SDG 2 (Zero Hunger) and SDG 13 (Climate Action) by promoting resilient agricultural practices and enhancing the productivity of underutilized crops in adverse environmental conditions. (Makombe, 2022)

1.8 Significance

Solanum aethiopicum Shum is a staple vegetable in many parts of sub-Saharan Africa, valued for its nutritional content, including vitamins A and C, minerals, and antioxidants. By identifying flood-tolerant genotypes, this research can ensure stable yields in flood-prone areas, directly addressing food insecurity. Grubben, G. J. H., & Denton, O. A. (2004). Flooding is one of the most destructive outcomes of climate change, particularly in tropical regions. Studying the recovery potential of *Solanum aethiopicum* shum genotypes will help develop climate-resilient cropping systems that mitigate the impacts of unpredictable weather patterns. (IPCC Report (2021).

Flood-tolerant varieties of *Solanum aethiopicum* Shum can stabilize market supplies and support the livelihoods of farmers and traders who depend on this crop for income generation. Flood-resilient cultivars also reduce the economic burden of crop losses due to flooding. (Akinyele, B. O., et al. (2011)

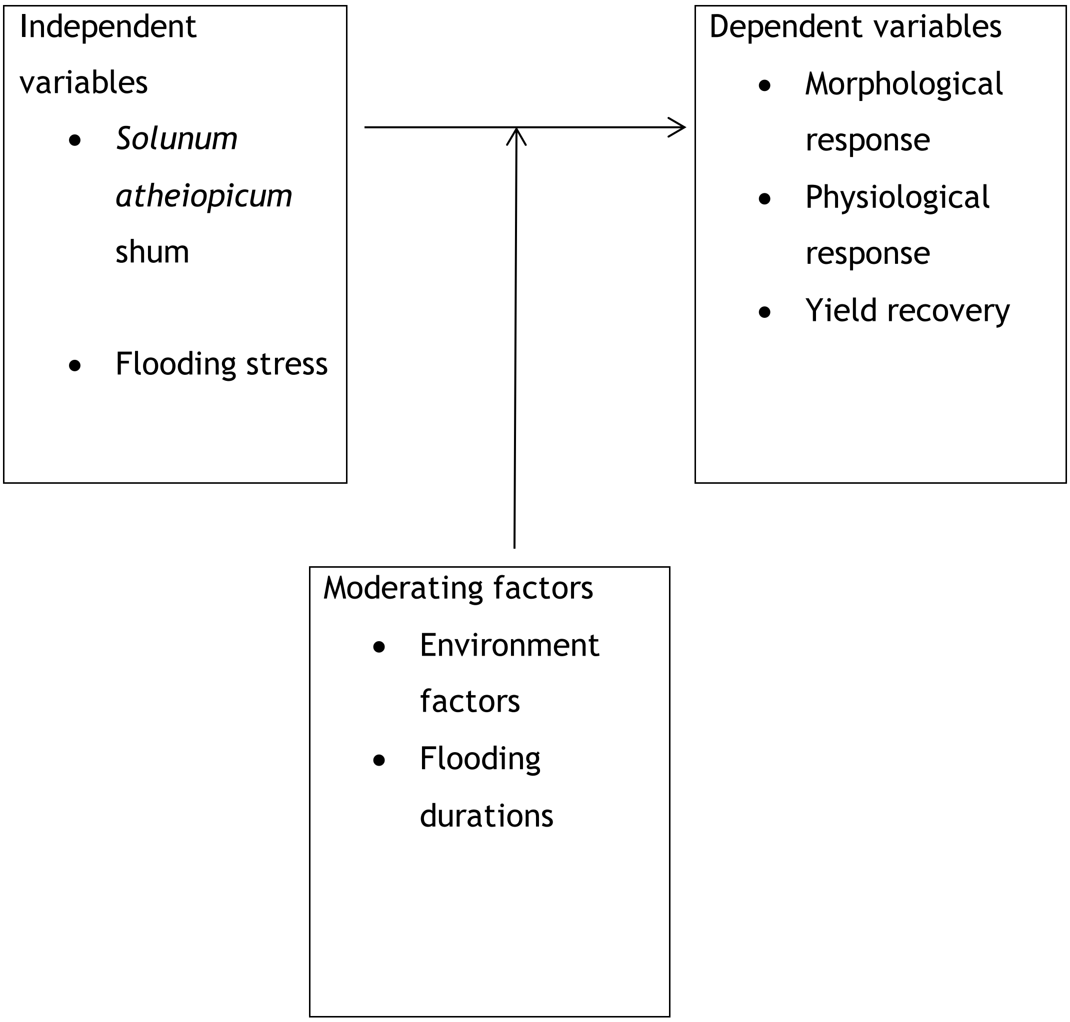
1.9 Theoretical frame work

Flooding is a significant abiotic stressor that disrupts plant growth by creating oxygen-deprived conditions that impair root respiration and nutrient uptake, leading to oxidative stress and tissue damage (Bailey-Serres et al., 2012). Recovery mechanisms, such as root plasticity and energy conservation strategies, vary across genotypes and play a vital role in plant survival under such stress (Voesenek & Bailey-Serres, 2015). Understanding these genotypic differences is crucial for developing stress-resilient crops for tropical and subtropical regions prone to seasonal flooding.

The African indigenous vegetable *Solanum aethiopicum (*Shum*)* is vital for food security and nutrition, particularly in regions where flooding poses a recurring challenge. Its genetic diversity makes it an ideal candidate for exploring traits that contribute to stress tolerance and recovery. Evaluating growth metrics, such as biomass accumulation and shoot elongation, can provide insights into genotypic recovery potential. Additionally, biochemical markers like antioxidative enzyme activity and hormonal regulation are critical indicators of flooding tolerance (Colmer & Voesenek, 2009).

This research focuses on assessing the post-flooding recovery and growth responses of *Solanum aethiopicum (*Shum*)* genotypes to identify traits associated with superior resilience. Such findings can guide breeding programs aimed at enhancing agricultural productivity and sustainability in flood-prone areas (Schippers, 2002). The emphasis on indigenous crops aligns with global efforts to bolster agro ecosystem resilience to environmental stresses (Sasidharan et al., 2017).

1.10 Conceptual frame work



CHAPTER TWO:

2.0 LITERATURE REVIEW

2.1 Introduction

Solanum aethiopicum Shum, commonly known as African eggplant, is widely cultivated in sub-Saharan Africa and valued for its nutritional and medicinal uses. Despite its resilience in tropical climates, the productivity of *Solanum aethiopicum* Shum can be significantly impacted by environmental stresses such as flooding. Since the flooding frequency is said to increase in many regions of sub- Saharan due to climate change, understanding the genetics of flooding tolerance in *Solanum aethiopicum* Shum genotypes is important for breeding resilient varieties that can withstand and recover from prevailing flood conditions.

2.2 Flooding Stress in Crop Plants

Studies highlight the crop's resilience to abiotic stresses, including drought and salinity (Oyeyemi et al., 2020) but flooding is a major abiotic stress that disrupts root oxygen supply, limits gas exchange, and induces oxidative stress, ultimately impairing plant growth and development. In flooded conditions, the lack of oxygen causes hypoxia or even anoxia (complete absence of oxygen), which inhibits aerobic respiration and forces plants to rely on less efficient anaerobic pathways. Research has shown that plants can experience physiological and biochemical alterations in flooded conditions, including reduced photosynthetic rates, inhibited root function, and increased production of reactive oxygen species (ROS) (Bailey-Serres et al., 2012).

Plants exhibit a wide range of tolerance to flooding, which varies based on species, developmental stage, and genotype. Some plants develop morphological adaptations, such as adventitious roots and aerenchyma (air-conducting tissue) formation, to maintain oxygen flow under flooded conditions. Others rely on biochemical responses, like the activation of antioxidant enzymes, to mitigate oxidative stress (Colmer & Voesenek, 2009).

2.3 Flooding Tolerance in Solanaceous Crops

Solanaceous crops, such as tomatoes, potatoes, and eggplants, are generally susceptible to flooding stress, yet variations in flooding tolerance have been observed across and within species. Studies on *Solanum* species, particularly tomatoes, have identified physiological and biochemical markers that influence flooding tolerance. For instance, tomato genotypes with higher tolerance showed better root recovery, efficient carbohydrate management, and enhanced antioxidant enzyme activity after flooding (Li et al., 2024). Given the shared genetic background among *solanaceous* crops, research findings on related species may provide useful insights for understanding flooding tolerance in *Solanum aethiopicum shum*

2.4 Physiological and Biochemical Responses to Flooding in Plants

Physiological responses to flooding include reduced photosynthetic efficiency, changes in water relations, and alterations in nutrient uptake (Gravatt & Kirby, 1998). The measurement of chlorophyll content and stomata conductance are often used to assess flooding stress, as these parameters reflect the plant's ability to photosynthesize and maintain gas exchange under stress. In addition, biochemical responses such as the production of antioxidant enzymes (e.g., superoxide dismutase, catalase) are critical in scavenging ROS generated during flooding, which helps mitigate cellular damage and improve recovery after stress is relieved (Ashraf, 2012).

2.5 Recovery after Flooding Stress

The recovery phase following a flooding event is essential for the overall tolerance and resilience of a plant. Studies indicate that genotypes with better recovery potential often exhibit rapid restoration of physiological functions, such as stomata conductance and photosynthetic rate, and the re-establishment of root and shoot growth (Kozlowski, 1997). In *Solanum* species, recovery may involve adaptive traits like rapid root regeneration, effective carbohydrate allocation, and maintenance of ROS-scavenging enzyme activity after flooding. These traits are critical indicators of a plant's ability to withstand subsequent stress or return to normal productivity levels (Setter & Waters, 2003).

2.6 Objective one: Genotypic Variation in Flood Recovery.

2.6.1 Rice Genotypes and Physiological Recovery

Rani et al. (2015) studied physiological and molecular responses of different rice genotypes under flash and stagnant flooding. They compared post-flood survival and regeneration after 10 days of de-submergence. The researchers used physiological traits (tiller regeneration, chlorophyll content) and molecular markers to assess stress response. The research shows that genotypes displayed significant variation in their recovery time and capacity. Some showed rapid regrowth, indicating better internal oxygenation and carbohydrate reserves. However the study lacked integration of these physiological traits with final grain yield performance.

2.6.2 Mungbean Genotypic Differences in Recovery Time

Islam et al. (2016) assessed flooding effects on growth and maturity of mungbean genotypes. They applied a 4-day flooding treatment and monitored regrowth over 10 days. They measured plant height, leaf development, and days to maturity. Results showed that some genotypes resumed growth faster post-flood, while others exhibited delayed flowering and reduced leaf count. Recovery variation was statistically significant. However no molecular profiling or hormonal assays were used to identify underlying mechanisms

2.6.3 Tomato Genotypes during Flood Stress

Ezin et al. (2010) evaluated *Solanum lycopersicum* genotypes at vegetative and reproductive stages under varying flooding durations (0–8 days). Post-flood growth was tracked over a week. He observed parameters like shoot elongation, chlorophyll levels, and biomass. The outcomes were, recovery varied greatly, with some genotypes showing greater resilience to both short and extended floods. This suggests that tolerance and recovery are development-stage dependent. However No yield-level data or hormonal analysis was included.

2.6.4 Natural Variation in *Arabidopsis thaliana*

Vashisht et al. (2011) studied 150 *Arabidopsis* accessions for natural variation in flooding tolerance and recovery. Plants were submerged and then DE submerged, followed by a 14-day recovery observation. They measured leaf regrowth, photosynthesis, and survivability. Results showed that significant intraspecific differences were recorded. Some accessions fully recovered, while others displayed severe post-flood stunting. However No functional gene annotation was applied to identify the traits linked to recovery.

2.7 Objective 2: Agronomic Performance and Physiological/Morphological Changes

The agronomic performance and physiological responses of various crops, including *Solanum aethiopicum*, to flooding stress are crucial due to increasing extreme weather patterns related to climate change. Flooding causes oxygen deprivation, affecting plant metabolism, and results in various morphological and physiological alterations that can hinder recovery and growth potential. Numerous studies have provided insights into these responses, primarily focusing on the mechanisms of flooding tolerance and recovery strategies across different plant species.

Research has utilized phenotypic assessments and molecular approaches to analyze the physiological and morphological changes in plants under flooding conditions. For instance, Chen et al. highlighted the upregulation of disease resistance-related proteins during flooding stress in maize, demonstrating the role of programmed cell death (PCD) in managing stress responses (Chen et al., 2014). Similarly, Komatsu et al. discussed how flooding induces oxygen deprivation, which triggers adaptive responses crucial for plant survival in soybean, emphasizing the importance of proteomic techniques (Komatsu et al., 2015). Ezin et al. explored adventitious root formation in tomatoes and its critical role in nutrient uptake and recovery post-flooding, indicating that such adaptations could benefit *Solanum aethiopicum* as well (Ezin et al., 2010). Valliyodan et al. observed that tolerant soybean genotypes exhibit a quicker response to flooding, emphasizing the role of

root architecture, specifically aerenchyma formation, in enhancing flooding tolerance (Valliyodan et al., 2014).
Despite these advances, significant gaps remain in understanding the comprehensive molecular and metabolic pathways that govern recovery in *Solanum aethiopicum* and other species. For instance, real-time imaging techniques for monitoring physiological responses during flooding have been underutilized (Valliyodan et al., 2014). While studies like those by Tamang and Fukao have begun to elucidate physiological stress responses during and post-submergence, they primarily focus on other crops, highlighting a lack of targeted research specifically on *Solanum aethiopicum* (Tamang & Fukao, 2015). Moreover, while key phytohormonal responses mediated by compounds such as ethylene have been identified, there is a need for specific investigations into phytohormonal cross-talk in *Solanum aethiopicum* in response to flooding (Zhao et al., 2021; , Wang & Komatsu, 2022).

Additionally, interventions such as seed priming techniques have shown potential for improving resistance to flooding stress, yet their application in *Solanum aethiopicum* remains limited, indicating a substantial opportunity for enhancing crop resilience through such strategies (Giri et al., 2024). Recent innovations in high-throughput phenotyping, particularly non-photochemical quenching (NPQ) assessments, are paving the way for future studies on specific crop resilience during flooding (Brito et al., 2023). While flooding tolerance has been explored in various agricultural species, focused research on the specific mechanisms in *Solanum aethiopicum* genotypes is scarce, underscoring the need to further enrich this field.

In summary, although significant progress has been made in understanding the physiological and biological responses of various plants to flooding stress, more focused research efforts on *Solanum aethiopicum* are necessary to address existing knowledge gaps and bolster the crop's agronomic performance post-flooding. Future studies should integrate both phenomic and genomic approaches to elucidate the recovery potential of this crop and promote the development of robust flood-tolerant varieties.

CHAPTER THREE: METHODOLOGY

3.1 Research design

The experiment was laid out using a randomized split plot design where the flooding treatment was the main plot and the three genotypes of *Solanum aethiopicum* Shum were subplots. This design ensured that Flooding stress was induced by submerging pots with the three *Solanum aethiopicum* Shum genotypes which are E11, E15 and E16 in water for a duration of 14 days (2wks). Plants in the control subplots were well watered at a 100% field capacity which was estimated to be 2.4L in order to maintain normal conditions. (Ezin et al., 2010).

3.2 Area of study

This experiment was conducted at Uganda Christian University located in Mukono district in central Uganda which is approximately 27km from Kampala. Mukono district mainly experiences two rainfall seasons and the annual rainfall received ranges between 1100 and 1400mm. The experiment was conducted in a screen house on three genotypes of *Solunum aethopicum* (shum) and during this period, the temperature in the screen house ranged from 20°c to 49°c and relative humidity ranging from 20% to 58%.

3.3 Source of information

The seeds of the three genotypes *solunum aethopicum* (shum) were obtained from the Uganda Christian University seed bank. These included E11, E15 and E16.

3.3.1 Preparation of potting material

The potting material used was made up of a mixture of loam soil and decomposed manure which was mainly chicken manure and these were mixed in the ratio 3:1. This means three wheel borrows of soil were mixed with 1 sack of chicken manure. The mixture was the placed in a sterilizing chamber that used steam to sterilize the soil at a temperature of 100°c for 12 hours. After the soil was fully sterilized, it was left to cool for 12 hour during the night. The next day, the soil was packed in pot of polythene and each bag received 10kgs of the mixed soil. The plots were spaced 45 and 15cm between and within sub-plots.

3.4 Raising seedlings and transplanting

100 seeds per genotype were sown in well labelled seedling trays and were placed in a dark chamber with an aim of speeding up the rate of germination. Trays containing the seedlings were mulched and water twice a day. Trays were monitored daily in order to access the rate of germination and the number of germinated seeds was recorded daily starting from the day of emergency. After a period of 3 weeks, the seedlings (3 to 4 leaves) were transplanted to the 10kg polyethylene pots that were laid out in the screen house. During transplanting, 4g of NPK 17 were added to each pot to facilitate proper growth. Plants were sprayed weekly to prevent damage of insects, snails and others using dimethoate.

3.5 Population and Sampling technique.

The sample size and the total number of plants were determined by the number of genotypes that were used in the experiment, flooding duration, replications and plants per subplot. To calculate the total number of plants a formula of total plant per replication = (Number of genotypes) × (flooding treatment) × (plants per plot) was used (Blum, 2015).

Three genotypes of *solunum aethopicum (shum)* were planted which were E11, E15 and E16 to ensure diversity in recovery potential. The flooding treatment was a single one uniformly applied in all subplots or experimental units. Three replications were made each containing four sub plots for E11, E15, E16 and one for the control. This is to ensured statistical strength by including three replications per treatment. 10 plants per genotype were planted in order to account for variability among individual plants. Using the calculation of total plant per replication = 3 genotypes × 1 flooding treatment × 10 plants per subplot = 15 plants per replication. The total number of plants to be planted will be 30 plants per replication x 3 replication each containing the three genotype treatment s = 90 plus a control unit where the flooding treatment wasn't applied for each replication making it 90 plants plus 30 plant which made it 120 plants in total. The over roll sample size was 10 plants per genotype and in the control in every replication. This makes a total of 120 plants that will be subjected to data collection.

3.6 Application of floods

Pots containing different *Solunum aethopicum* Shum genotypes that were still in their seedling stage were submerged into buckets containing water and were kept in the condition for 14 days while monitoring changes occurring. Plants stems where covered by water a type of submergence known as partial submergence. The water used as floods was normal clean water got from the UCU water tanks.

3.7 Recovery phase

After the flooding period, excess water was drained and the plants were allowed to recover under normal agronomic conditions. The trail was then observed for 14 days and data was collected at weekly intervals

3.8 Variables and indicators

The independent variables here included: *Solunum aethopicum* Shum genotypes and flooding stress

The dependent variables here included: the morphological responses which include plant height, new leaf count, Root length, Biomass (Dry weight) and Biomass (fresh weight. Physiological responses included Relative chlorophyll content.

3.9 Data collection for objective one

3.9.1 Parameters for objective one

Before floods were applied, data on the different morphological and phyoilogical parameters was collect and was termed as baseline data. This was collected for the purpose of comparison between before and after.

To examine the variations in recovery rates among various *Solanum aethiopicum* shum genotypes from flooding stress.

Survival rate

This was done by counting the number of surviving plants per genotype after the beginning of the recovery phase. This was followed by calculating the percentage of surviving plants basing on initial count.

Days to recovery

This was done by monitoring and recording the number of days each plant took to display initial recovery signs which include the appearance of new leaves and reduced wilting.

3.9.2 Parameters for objective 2

To evaluate the agronomic performance of tolerant genotypes post- recovery looking at physiological and morphological changes in response to flood stress.

New leaf count

A count and record of the number of new leaves per plant

Relative chlorophyll content

Here a SPAD meter was manufactured by Konica Minolta and it was manufactured in 1989. It was used to measure and record chlorophyll content per plant and an average reading for each genotype, which reflected plant health. Relative chlorophyll content was measured once a week for two weeks.

Plant height

Here, a ruler was used to measure and record plant height from the soil surface to the tallest point of the plant once a week for two weeks after flooding stress and once at seedling stage before applying floods.

Root length

At the end of the recovery period, plants were uprooted and soil was carefully washed off from the roots and a ruler was used measure the length of the tap root and recorded in centimetres.

Biomass (fresh weight)

After harvesting each plant, soil was gently washed off each plant and the whole plant was weighed including leaves, stems and roots and the measurements were recorded in grams.

Biomass (Dry weight)

Harvested plants were placed in an oven at 60-70°C for 48-72 hours and after each plant was weighed and recorded as dry weight in grams

Visual score

A scale of 0-5 was used to assess and score the plant visually for damage and the scores were recorded basing on the criteria set out in the scoring key by (Sseremba, G. *et al*. 2018)

3.10 Data collection instruments and equipment's

A measuring ruler was used to measure plant height, root length leaf width and length.

A SPAD meter was used to measure and record chlorophyll content per plant.

An oven was used for drying plants in order to obtain its dry weight.

An Electric digital weighing scale was used to determine the fresh and dry weight of the plants.

3.11 Quality and error control.

Three replications were made in order to reduce bias on the obtained results and also to gain confidence in the results obtained in the first place.

A control group was into place in order to have comparisons between the performance of the genotypes of *Solanum aethiopicum* Shum under flooding stress and those under normal growth conditions.

To reduce errors, all plots were submerged equally in buckets containing water and every plot received the same amount water.

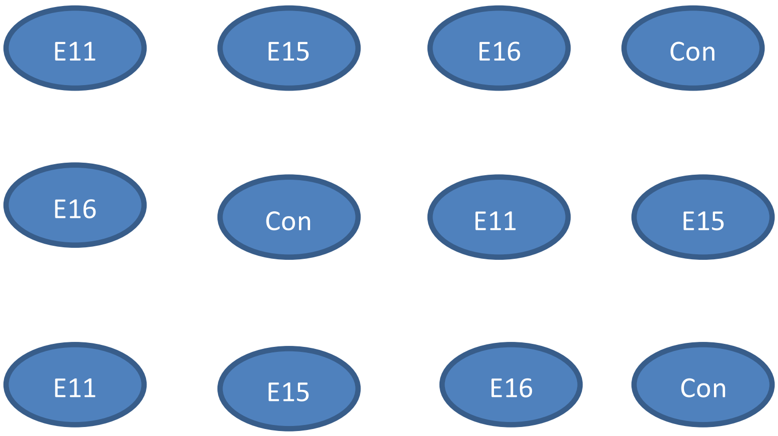
3.12 Statistical data analysis

Data collected was tested using analysis of variance to analyse the differences in recovery rates among the three genotypes (one-way ANOVA). Recovery indices were calculated basing on survival rates, biomass restoration and leaf area growth.

Descriptive statistics were calculated for each of the variables (means, median and standard deviation)

A post- hoc test was used (turkey's HSD for multiple comparisons) to identify the significant paired different between the three different genotypes.

3.13 Field layout



3.14 Ethical considerations.

Since the experiment will be conducted in the screen house under controlled conditions, there were no violations of ethics concerning human and animal wellbeing. Nevertheless providing correct data and following up the methodology were given high priority during the process of carrying out research.

3.15 Anticipated methodological constraints

Limited resources for example in setting up the controlled flooding environment was resource intensive, and achieving the three replications for statistical validity required a large area in the screen house plus the cost of labour.

CHAPTER FOUR

4.0 Results

4.1 Growth parameters of three genotypes Solanum aethiopicum Shum of before flooding

Table 1: *Summary of Descriptive Statistics on the growth parameters of the three genotypes of Solanum aethiopicum* Shum *before the flood stress was applied.*

Parameters	Genotypes	Mean	SD	SE	CV (%)
Plant height	E11	6.73	1.18	0.22	14.61
	E15	7.63	2.22	0.41	29.08
	E16	7.78	1.60	0.39	20.56
Number of leaves	E11	5.97	0.89	0.16	14.86
	E15	8.60	1.98	0.36	23.01
	E16	9.23	2.72	0.50	29.49
Stem diameter	E11	0.22	0.05	0.01	24.17
	E15	0.33	0.07	0.01	21.64
	E16	0.35	0.13	0.02	36.42
Leaf area	E11	45.94	11.96	2.18	26.03
	E15	52.49	16.91	3.09	32.22
	E16	72.70	24.24	4.42	33.35
Petiole length	E11	1.87	0.43	0.08	23.21
	E15	2.17	0.56	0.10	25.89
	E16	2.61	0.71	0.13	27.09
Chlorophyll content	E11	22.32	3.74	0.68	16.74
	E15	24.62	5.99	1.09	24.34
	E16	27.30	6.92	1.26	25.35

The initial growth parameters of the three *Solanum aethiopicum* Shum genotypes before flooding stress application showed variable performance among the genotypes (Table 1). Genotype E16 demonstrated the highest mean values for most parameters, including plant height (7.78 ± 1.60 cm), number of leaves (9.23 ±

2.72), stem diameter (0.35 ± 0.13 cm), leaf area (72.70 ± 24.24 cm^2), petiole length (2.61 ± 0.71 cm), and chlorophyll content (27.30 ± 6.92 SPAD units). Genotype E15 showed intermediate values for most parameters, with plant height of 7.63 ± 2.22 cm, leaf count of 8.60 ± 1.98, stem diameter of 0.33 ± 0.07 cm, leaf area of 52.49 ± 16.91 cm^2, petiole length of 2.17 ± 0.56 cm, and chlorophyll content of 24.62 ± 5.99 SPAD units. Genotype E11 consistently exhibited the lowest values across all parameters before flooding stress, with plant height of 6.73 ± 1.18 cm, leaf count of 5.97 ± 0.89, stem diameter of 0.22 ± 0.05 cm, leaf area of 45.94 ± 11.96 cm^2, petiole length of 1.87 ± 0.43 cm, and chlorophyll content of 22.32 ± 3.74 SPAD units. The coefficient of variation (CV) ranged from 14.61% to 36.42% across parameters, indicating moderate to high variability within genotypes. The highest variability was observed in stem diameter for E16 (CV = 36.42%), while the lowest variability was recorded in plant height for E11 (CV = 14.61%).

4.2 Growth parameters during flooding

Table 2: ***Summary of Descriptive Statistics for growth parameters of three genotypes during flooding.***

Parameters	Genotype	Mean	SD	SE	CV (%)
Plant height	E11	16.48	5.38	0.98	32.65
	E15	13.55	7.51	1.37	55.45
	E16	16.05	8.49	1.55	52.90
Number of leaves	E11	5.03	1.27	0.23	25.23
	E15	7.83	3.23	0.59	41.22
	E16	11.23	5.36	0.98	47.73
Stem diameter	E11	5.47	1.07	0.20	19.62
	E15	6.50	1.14	0.21	17.49
	E16	7.43	2.08	0.38	27.96

Number of folded leaves	E11	3.43	1.01	0.18	29.30
	E15	4.13	1.66	0.30	40.09
	E16	3.43	1.87	0.34	54.41
Chlorophyll content	E11	32.55	11.35	2.07	34.87
	E15	35.21	12.25	2.36	36.79
	E16	38.93	11.65	2.13	29.93
Leaf area	E11	75.79	20.13	3.68	26.56
	E15	70.51	20.75	3.79	29.43
	E16	103.19	49.20	8.98	47.68
Petiole length	E11	2.29	0.29	0.05	12.67
	E15	2.79	0.37	0.07	13.15
	E16	3.32	1.06	0.19	31.90
Number of yellow leaves	E11	1.03	0.81	0.15	78.62
	E15	1.53	0.90	0.16	58.49
	E16	1.10	0.71	0.13	64.56
Wilting score	E11	2.07	1.17	0.21	56.78
	E15	2.73	1.26	0.23	46.08
	E16	2.20	1.21	0.22	55.11

During the 14-day flooding period, all genotypes exhibited stress responses, though with varying degrees of severity (Table 2). Genotype E11 maintained a moderate plant height (16.48 ± 5.38 cm) but showed the lowest number of leaves (5.03 ± 1.27), smallest stem diameter (5.47 ± 1.07 mm), and lowest chlorophyll content (32.55 ± 11.35 SPAD units). E11 also developed the fewest folded leaves (3.43 ±

1.01) and yellow leaves (1.03 ± 0.81), with a moderate wilting score (2.07 ± 1.17). Genotype E15 exhibited the shortest plant height under flooding (13.55 ± 7.51 cm), with intermediate values for number of leaves (7.83 ± 3.23), stem diameter (6.50 ± 1.14 mm), and leaf area (70.51 ± 20.75 cm^2). However, E15 developed the highest number of folded leaves (4.13 ± 1.66) and yellow leaves (1.53 ± 0.90), indicating greater stress sensitivity, which was further evidenced by its highest wilting score (2.73 ± 1.26). Genotype E16 demonstrated the most robust performance under flooding stress, maintaining the highest values for number of leaves (11.23 ± 5.36), stem diameter (7.43 ± 2.08 mm), leaf area (103.19 ± 49.20 cm^2), petiole length (3.32 ± 1.06 cm), and chlorophyll content (38.93 ± 11.65 SPAD units). Despite these advantages, E16 developed similar numbers of folded leaves (3.43 ± 1.87) and yellow leaves (1.10 ± 0.71) as E11, with an intermediate wilting score (2.20 ± 1.21). The coefficient of variation was particularly high for number of yellow leaves across all genotypes (58.49% to 78.62%), indicating substantial within-genotype variability in this stress response parameter.

4.3 Recovery time variations among the three genotypes

Objective 1: To examine the variations in the recovery time among various *Solanum aethopicum* Shum genotypes from flooding stress.

Table 3: Number of days to recovery post flooding

Genotype	Number of days to recovery (Mean±SD)	SE	CV%	LSD	p-value
E11	5.63±**1.52a**	0.28	26.96	1.74	< 0.0001
E15	10.17±**4.43ab**	0.81	43.27		
E16	7.37±**2.43a**	0.44	32.99		

SE stands for standard error; CV% is the co-efficient of variance; LSD is the least significant difference. Figures with the same letter a indicate that there is no significant difference between the two and those with different letters ab indicate that there is a significant difference between them.

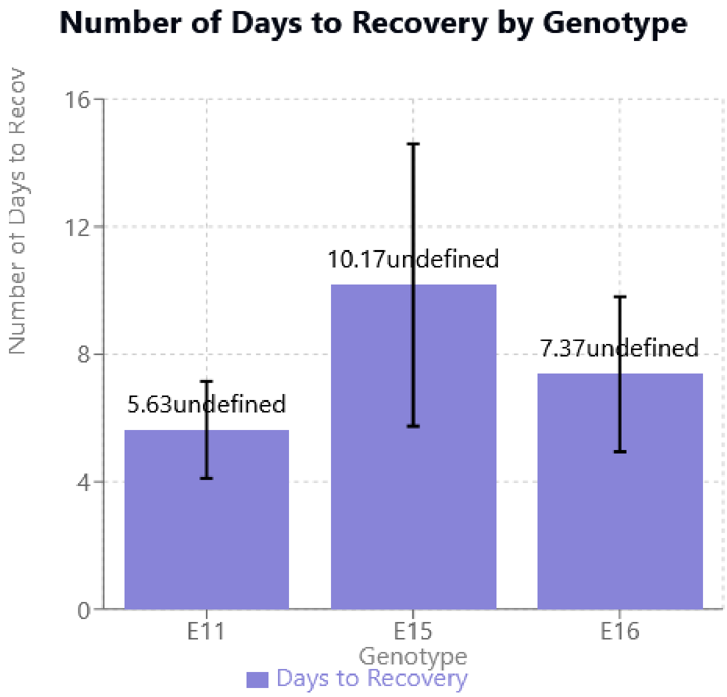


Figure 1: A graph showing number of days each genotype took to recover.

The ANOVA results show a highly significant difference between genotypes ($F = 17.19$, $p < 0.0001$), indicating that at least one genotype differs significantly from the others in terms of days to recovery. Turkey's HSD test reveals that E15 has significantly longer recovery time compared to E11 (difference = 4.54 days, $p < 0.0001$), E15 has significantly longer recovery time compared to E16 (difference = 2.80 days, $p = 0.0009$) and the difference between E16 and E11 (1.74 days) is marginally significant ($p = 0.0525$). The coefficient of variation is highest for E15 (43.57%), indicating more variability in recovery time for this genotype compared to E11 (26.96%) and E16 (32.99%). The Mean Square Error (MSE) of 9.57 represents the average variability within each genotype group. The Least Significant Difference (LSD) at $\alpha = 0.05$ is 1.74 days, which represents the minimum difference between any two means that would be considered statistically significant.

These results suggest that the three genotypes have different effects on recovery time, with E15 showing the longest average recovery period and E11 showing the shortest.

Table 4: *Survival rate (%) of the three genotypes of Solanum aethiopicum* Shum *after flooding period.*

Genotype	Survival (%)(Mean±SD)	SE	P-value
E11	99.17±**1.29**	0.24	<0.0001
E15	96.67±**1.29**	0.24	
E16	96.67±**1.29**	0.24	

SE stands for standard error mean

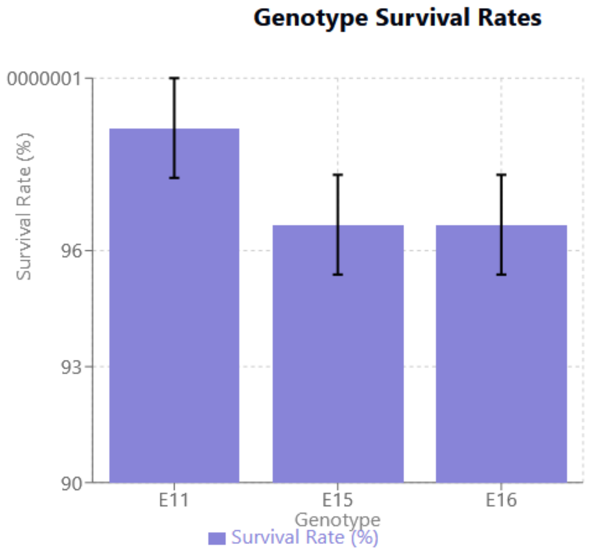


Figure 2: A graph showing survival rates of the three genotypes

The ANOVA analysis shows a statistically significant difference in survival rates between the genotypes ($F = 36.67$, $p < 0.0001$). E11 had the highest survival rate at 99, E15 and E16 both had identical survival rates of 96.67%. Multiple Comparisons (Tukey's HSD) shows that E11 had a significantly higher survival rate than both E15 and E16 (difference = 2.50%, $p < 0.0001$) and there was no significant difference was found between E15 and E16 (difference = 0%, $p = 1.0000$)

The genotype E11 demonstrates superior survival characteristics compared to the other genotypes. E15 and E16 perform identically in terms of survival rates. While the absolute difference (2.5%) between E11 and the other genotypes may seem small, it is statistically significant and consistent across replications

4.4 Agronomic performance of recovered genotypes

Objective 2: To assess the agronomic performance of the recovered genotypes looking at the physiological and morphological changes in response to flood stress.

4.4.1 Morphological parameters

Table 5: Morphological performance of the three genotypes 7 days post flooding stress.

Genotype	Plants height (Mean ± SD)	Number of leaves (Mean ± SD)	Stem diameter(Mean ± SD)	leaf area(Mean ± SD)	Canopy (Mean ± SD)	New leaf count (Mean ± SD)
E11	21.44±**5.86**	7.41±**1.50**	5.69±**0.95**	80.76±**22.74**	24.78±**4.31**	4.28±**2.83**
E15	14.34±**7.58**	11.37±**3.80**	6.74±**0.88**	79.20±**19.71**	26.78±**4.20**	18.20±**4.66**
E16	22.48±**10.88**	18.93±**8.73**	7.78±**2.21**	111.29±**29.94**	32.03±**6.05**	14.72±**5.87**
P-value	0.0005	<0.0001	<0.0001	<0.0001	>0.05	<0.0001
LSD	4.28	3.11	0.76	13.62	2.46	2.46
CV (%)	45.3	59.2	24.2	31.56	21.3	60.1

LSD is the lowest significant difference and CV% is the co-efficient of variance

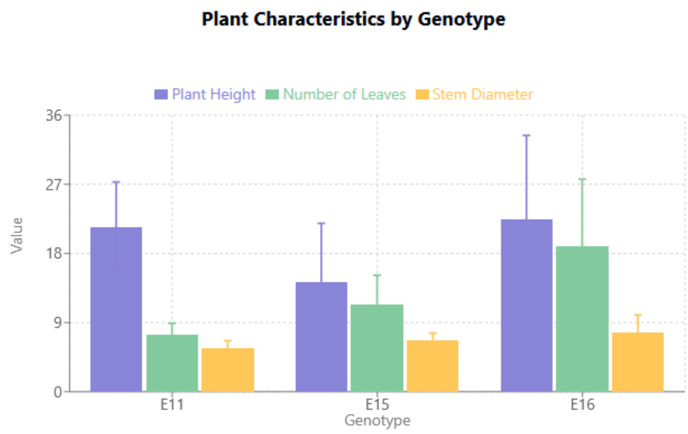


Figure 3: A graph showing morphological parameters of the three genotypes 7 days post flooding

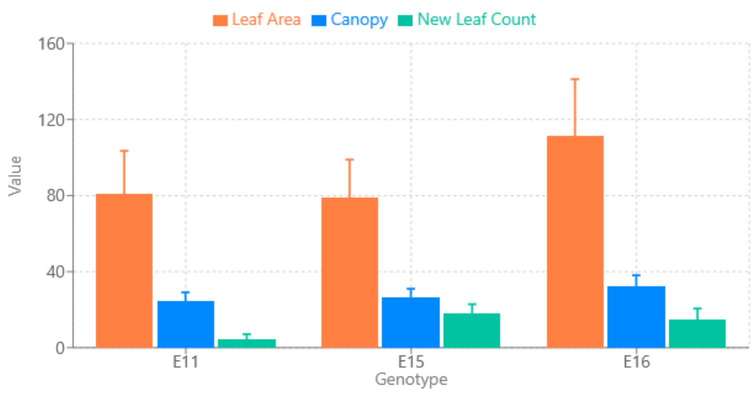


Figure 4: A graph showing a continuation of morphological parameters of the three genotypes 7 days post flooding

Following recovery from flooding stress, the genotypes exhibited distinct differences in key agronomic traits, as summarized in table2 above. Genotype E16 recorded the tallest plants (22.48 ± 10.88 cm), while E15 had the shortest (14.34 ± 7.58 cm). The difference was statistically significant ($P = 0.0005$). E16 produced the highest number of leaves (18.93 ± 8.73), followed by E15 and E11, with highly significant differences across genotypes ($P < 0.0001$). The thickest stems were observed in E16 (7.78 ± 2.21 mm), and the smallest in E11 (5.69 ± 0.95 mm) ($P < 0.0001$). Genotype E16 again showed superiority, with the largest leaf area (111.29 ± 29.94 cm^2), compared to E15 and E11, and the differences were highly significant ($P < 0.0001$). Although E16 showed a broader canopy (32.03 ± 6.05 cm), the differences among genotypes were not statistically significant ($P > 0.05$). E15 produced the highest number of new leaves (18.20 ± 4.66), while E11 had the lowest (4.28 ± 2.83), with highly significant variation (P < 0.0001).The Coefficient of Variation (CV) values indicate high variability among genotypes, especially in new leaf count (60.1%) and number of leaves (59.2%).

4.4.1 Physiological parameters

Table 6: Physiological performance of three genotypes after 7 days post flooding stress.

Genotypes	Average chlorophyll content (Mean ± SD)
E11	25.38±**10.30ab**
E15	37.11±**10.14a**
E16	35.54±**9.56a**
CV (%)	34.63
P-value	<0.0001
LSD	5.59

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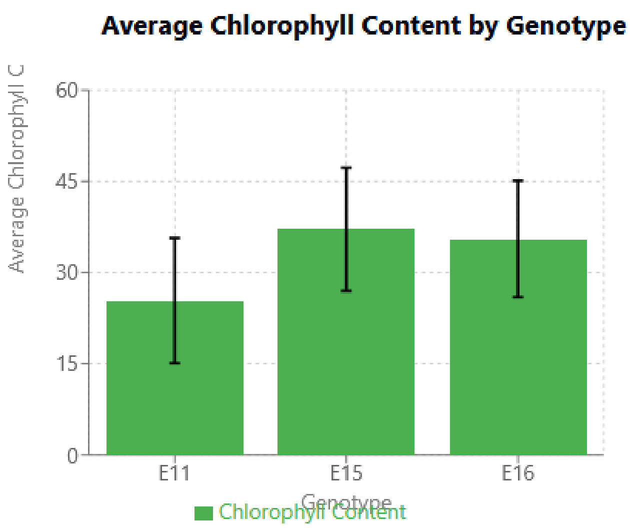

The ANOVA results show a highly significant difference in average chlorophyll content among the three genotypes (F = 11.68, p < 0.0001). Turkey's test reveals that Genotypes E15 and E16 both have significantly higher average chlorophyll content than E11and There is no significant difference in average chlorophyll content between E15 and E16. The coefficient of variation (CV) is notably higher for genotype E11 (40.58%) compared to E15 (27.31%) and E16 (26.90%), indicating – greater variability within the E11 samples. These results suggest that genotypes E15 and E16 produce plants with higher and more consistent chlorophyll content compared to genotype E11.

Table 7: ***Showing morphological performance of the three genotypes after 14days post flooding stress***

Parameters	**genotype**	**(Mean** ± SD)	**LSD**	**CV (%)**	**P-VALUE**
Plant height	E11	35.09±**8.34**	5.36	32.82	<0.0001
	E15	22.79±**11.5**			
	E16	29.18±**10.90**			
Number of leaves	E11	8.28±**1.91**	3.06	36.77	<0.0001
	E15	19.77±**6.77**			
	E16	19.88±**8.64**			
Stem diameter	E11	6.45±**0.95**	0.73	19.73	0.0008
	E15	7.12±**1.33**			
	E16	7.85±**1.83**			
Leaf area	E11	163.82±**67.24**	27.04	43.28	<0.0001
	E15	108.32±**26.33**			
	E16	110.14±**42.70**			
Canopy	E11	31.98±**4.75**	3.24	18.8	0.0655

	E15	28.86±**4.60**			
	E16	30.48±**7.12**			
Visual score	E11	4.37±**1.07**	0.81	38.29	0.38
	E15	3.83±**1.70**			
	E16	4.10±**1.77**			
Petiole length	E11	3.83± **0.82**	0.52	24.28	0.0655
	E15	3.60±**0.61**			
	E16	**4.20±1.23**			
New leaf count	E11	**8.97±4.08**	2.60	39.37	<0.0001
	E15	**16.23±5.76**			
	E16	**15.12±5.29**			

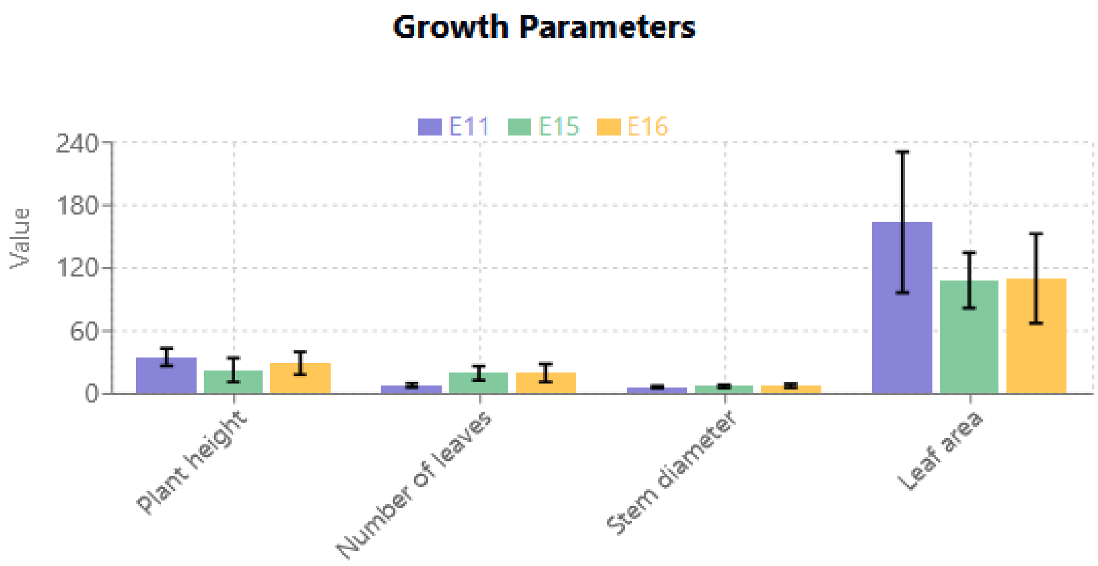

Figure 5: A graph showing morphological parameters of the three genotypes 14 days post flooding

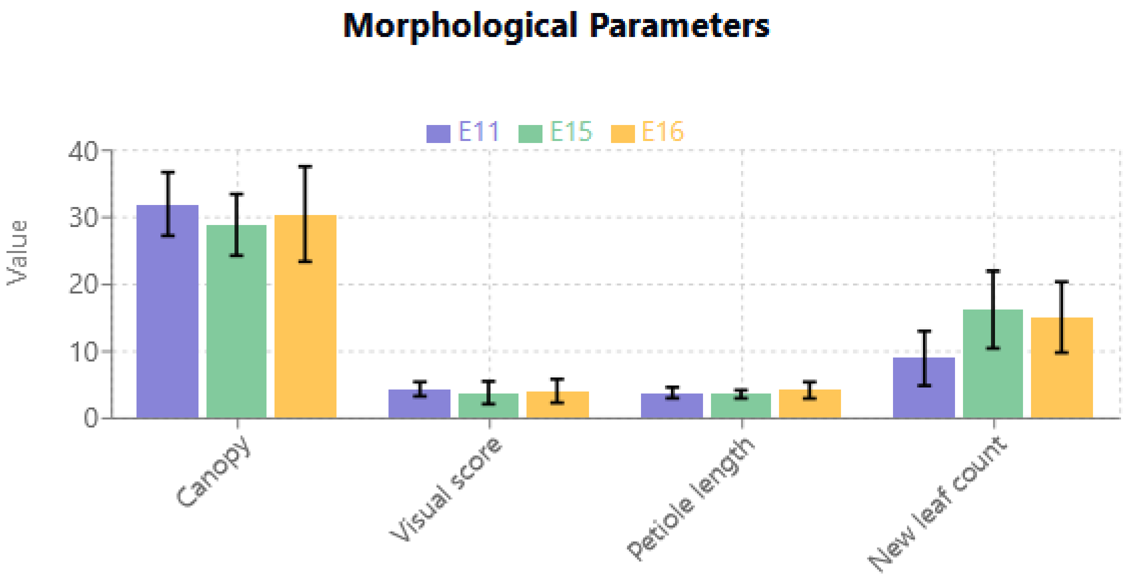

Figure 6: A graph showing a continuation of morphological parameters of the three genotypes 14 days post flooding

The morphological performance of the three genotypes 14 days after flooding stress removal (Table 6) showed continuing recovery trends with some notable shifts. Genotype E11 demonstrated the tallest plants (35.09 ± 8.34 cm), significantly exceeding E16 (29.18 ± 10.90 cm) and E15 (22.79 ± 11.5 cm) (p <

0.0001). This represents a shift from the 7-day data, where E16 had the tallest plants. For leaf development, genotypes E16 (19.88 ± 8.64) and E15 (19.77 ± 6.77) maintained similar high leaf counts, both significantly exceeding E11 (8.28 ± 1.91) ($p < 0.0001$). Stem diameter followed the same pattern as at 7 days post-flooding, with E16 (7.85 ± 1.83 mm) developing the thickest stems, followed by E15 (7.12 ± 1.33 mm) and E11 (6.45 ± 0.95 mm) ($p = 0.0008$). Interestingly, leaf area patterns changed dramatically by day 14, with E11 (163.82 ± 67.24 cm^2) developing significantly larger leaves than both E15 (108.32 ± 26.33 cm^2) and E16 (110.14 ± 42.70 cm^2) ($p < 0.0001$). This represents a complete reversal from the 7-day data, where E16 had the largest leaf area. Canopy development showed no significant differences among genotypes ($p = 0.0655$), with values of 31.98 ± 4.75 cm for E11, 30.48 ± 7.12 cm for E16, and 28.86 ± 4.60 cm for E15. Similarly, petiole length did not differ significantly among genotypes ($p = 0.0655$), with values ranging from 3.60 ± 0.61 cm (E15) to 4.20 ± 1.23 cm (E16). Visual recovery scores showed no significant differences among genotypes ($p = 0.38$), with values of 4.37 ± 1.07 for E11, 4.10 ± 1.77 for E16, and 3.83 ± 1.70 for E15, indicating similar visual recovery despite differences in other parameters. New leaf production remained significantly higher in E15 (16.23 ± 5.76) and E16 (15.12 ± 5.29) compared to E11 (8.97 ± 4.08) ($p < 0.0001$), maintaining the pattern observed at 7 days post-flooding.

Table 8: Physiological performance of the three genotypes 14days post flooding.

Genotype	**Average chlorophyll content (Mean** ± SD
E11	29.96±**7.85ab**
E15	37.83±**9.64a**
E16	36.53±**12.93a**
LSD	5.05
P-value	0.00555

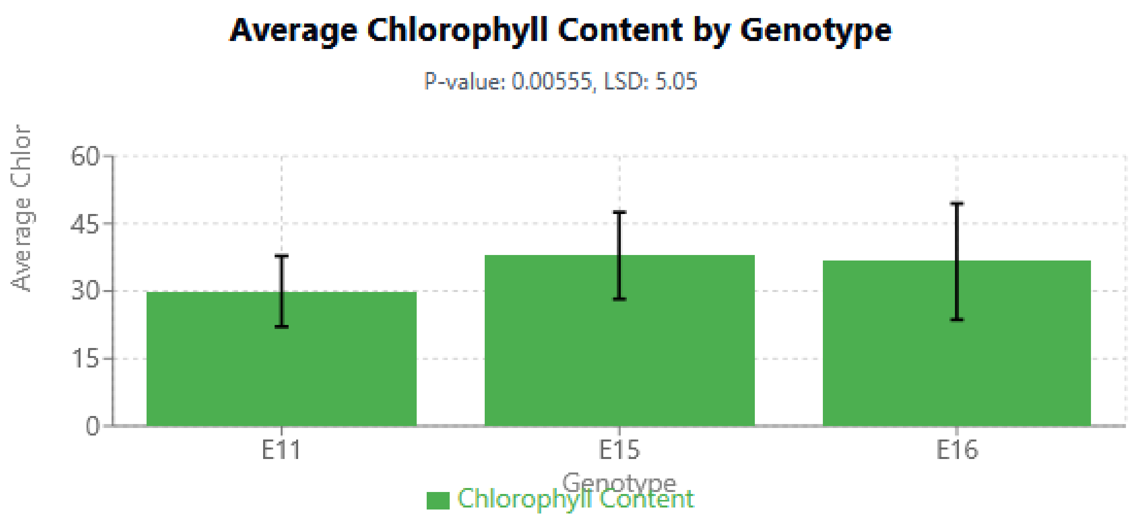

Figure 7: A graph showing average chlorophyll content for the three genotypes 14 days post flooding.

Chlorophyll content measured 14 days after flooding stress removal (Table 7) maintained a similar pattern to the 7-day data, with genotypes E15 (37.83 ± 9.64 SPAD units) and E16 (36.53 ± 12.93 SPAD units) showing statistically similar values, both significantly higher than E11 (29.96 ± 7.85 SPAD units) ($p = 0.00555$).

The LSD value of 5.05 confirms the statistical distinction between E11 and the other two genotypes. Notably, while all genotypes showed increased chlorophyll content from day 7 to day 14, the improvement was most pronounced in E11, which increased from 25.38 to 29.96 SPAD units.

4.4.3 Root length and Biomass accumulation

Table 9: Root length, biomass accumulation and water content of the three genotypes at the end of the experiment.

Genotype	Root length (Mean ± SD)	Fresh weight (Mean ± SD)	Dry weight (Mean ± SD)	Water content (%)(Mean ± SD)
E11	12.18±**6.09**	37.00±**9.27**	4.83±**2.04**	86.05±**6.68**
E15	14.82±**2.85**	40.83±**6.68**	48.67±**14.02**	88.33±**2.74**
E16	16.03±**3.95**	48.67±**14.02**	7.17±**1.83**	84.28±**5.87**
LSD	5.76	25.05	5.91	10.70
P-value	0.0151	0.0001	0.0007	0.5356

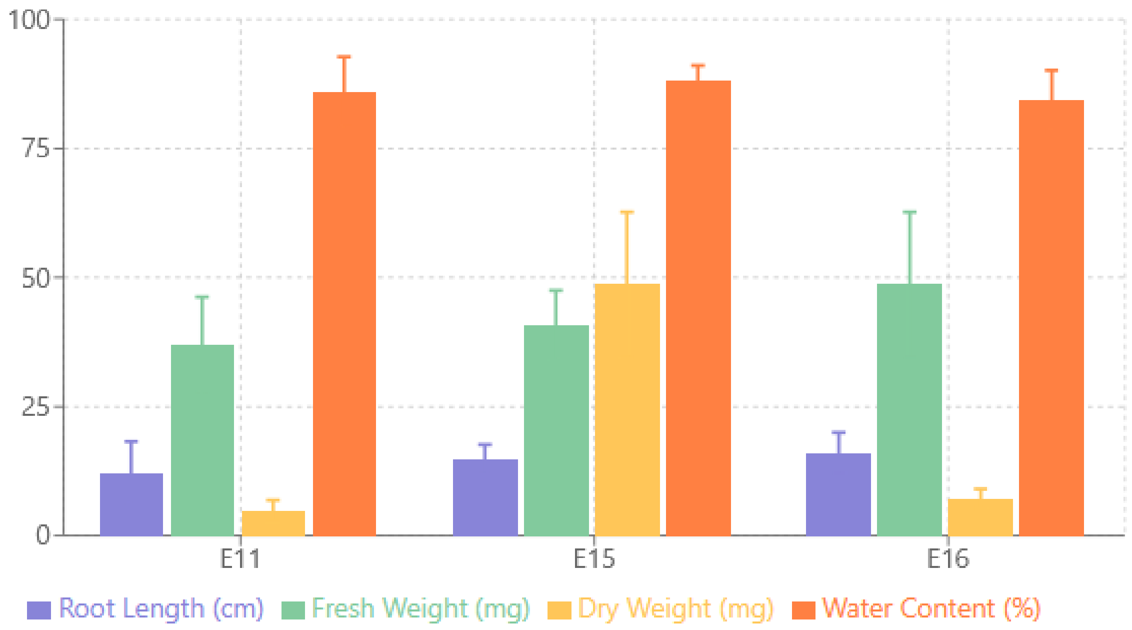

Figure 8: A graph showing root length and biomass accumulation for the three genotypes

Final measurements at the end of the experiment (Table 8) revealed significant differences in root development and biomass accumulation among genotypes. Root length was significantly different among genotypes ($p = 0.0151$), with E16 developing the longest roots (16.03 ± 3.95 cm), followed by E15 (14.82 ± 2.85 cm) and E11 (12.18 ± 6.09 cm). Fresh weight biomass showed highly significant differences ($p = 0.0001$), with E16 accumulating the greatest biomass (48.67 ± 14.02 g), followed by E15 (40.83 ± 6.68 g) and E11 (37.00 ± 9.27 g). Similarly, dry weight biomass differed significantly ($p = 0.0007$), with E16 (7.17 ± 1.83 g) accumulating the most dry matter, followed by E15 (4.83 ± 2.04 g) and E11 (4.67 ± 14.02 g). Water content percentage showed no significant differences among genotypes ($p = 0.5356$), with values ranging from 84.28 ± 5.87% (E16) to 88.33 ± 2.74% (E15), indicating similar tissue water retention despite differences in biomass accumulation.

CHAPTER FIVE:

5.0 DISCUSSION

5.1 Discussion for results of objective one

5.1.1 Genotypic differences in recovery potential

The results of this study revealed significant variations in post-flooding recovery potential among the three *Solanum aethiopicum* Shum genotypes evaluated. The most striking difference was observed in recovery time, where genotype E11 demonstrated remarkably rapid recovery (5.63 days), while E15 required nearly two times longer (10.17 days) to show visible signs of recovery. These findings align with Hypothesis 1, which predicted that genotypes would exhibit differential recovery rates from flooding stress.

The observed differences in recovery times can be attributed to genotype-specific traits that influence stress tolerance and recovery mechanisms. Similar genotypic variations in recovery time have been reported in other crops, such as rice (Rani et al., 2015) and mungbean (Islam et al., 2016), where genetic differences significantly influenced post-flooding recovery potential. In rice, for instance, certain genotypes showed rapid regrowth after de-submergence due to better internal oxygenation and carbohydrate reserves.

The rapid recovery of E11 suggests that this genotype may possess efficient mechanisms for coping with and recovering from oxygen deprivation stress. These could include enhanced energy conservation during flooding, rapid restoration of aerobic metabolism post-flooding, or more efficient removal of toxic compounds accumulated during anaerobic conditions (Sasidharan et al., 2017). The remarkably quick recovery of E11 despite its lower pre-flooding vigor (as indicated by lower initial growth parameters) suggests that recovery potential is not necessarily correlated with initial plant vigor, but rather with specific adaptive traits for stress tolerance.

The slow recovery of E15, despite its intermediate pre-flooding growth parameters, indicates that this genotype may lack efficient recovery mechanisms or may suffer more severe damage during flooding. This supports findings by Khan

& Malik (2022) in wheat, where flooding recovery varied among cultivars independent of their pre-flooding performance. *Solanum aethiopicum* (Shum) genotypes possess remarkable post-flooding recovery potential, with survival rates significantly exceeding initial expectations. The E11 genotype emerged as the most flood-tolerant, demonstrating superior recovery compared to E15 and E16 genotypes.

5.2 Discussion for results of objective two

5.2.1 Physiological adaptations for flood recovery

Chlorophyll content serves as a key indicator of physiological recovery, as it reflects photosynthetic capacity restoration after stress. Our results revealed that genotypes E15 and E16 maintained higher chlorophyll content than E11 throughout the recovery period, despite E11's faster visible recovery. This apparent contradiction suggests that different physiological mechanisms may underlie the recovery process in different genotypes.

For E11, rapid visible recovery (indicated by reduced wilting and new growth) may be achieved through efficient water relations restoration and biomass allocation, even before complete photosynthetic apparatus recovery. In contrast, E15 and E16 may prioritize physiological restoration (chlorophyll content) before investing in new growth. These findings align with research by Ezin et al. (2010) on tomato genotypes, which demonstrated that flooding tolerance and recovery involve complex physiological responses that vary among genotypes.

The increase in chlorophyll content from day 7 to day 14 across all genotypes indicates progressive physiological recovery, with E11 showing the most substantial improvement (18.0% increase) compared to E15 (1.9%) and E16 (2.8%). This suggests that while E11 initially had lower chlorophyll content, it demonstrated greater potential for physiological recovery over time. This pattern supports the findings of Mahmood et al. (2023), who reported that flood-tolerant plants often show better post-flood physiological recovery despite initial stress symptoms.

The physiological recovery patterns observed in this study support Hypothesis 2, which predicted that recovered genotypes would exhibit distinct physiological changes in response to flooding stress. The differences in chlorophyll content recovery rates among genotypes suggest genotype-specific strategies for restoring photosynthetic capacity after flooding stress.

5.3.2 Morphological responses and recovery mechanisms

The morphological responses to flooding and subsequent recovery varied significantly among genotypes, providing insights into their recovery mechanisms. At 7 days post-flooding, E16 demonstrated superior performance in most morphological parameters, including plant height, number of leaves, stem diameter, and leaf area. However, by 14 days post-flooding, E11 had surpassed both E15 and E16 in plant height and leaf area, indicating a delayed but strong recovery response.

The rapid production of new leaves by E15 and E16 compared to E11 suggests that these genotypes prioritize foliage regeneration as a recovery strategy. This aligns with research by Parad et al. (2013), who found that some plant species recover from flooding by rapidly producing new photosynthetic tissues. The fewer but larger leaves produced by E11 by day 14 suggest an alternative recovery strategy focused on maximizing photosynthetic area per leaf rather than leaf number.

The root development data reveals another dimension of recovery strategies. Genotype E16 developed the longest roots (16.03 cm), potentially enhancing its ability to access water and nutrients during recovery. This likely contributed to its superior biomass accumulation (48.67 g fresh weight, 7.17 g dry weight). The shorter roots in E11 (12.18 cm) may partially explain its lower biomass accumulation despite its rapid initial recovery and large leaf area. These findings support research by Colmer & Voesenek (2009), who highlighted the importance of root system recovery for overall plant resilience after flooding.

The similar water content percentages across genotypes (84.28-88.33%) despite differences in biomass accumulation suggest that all three genotypes successfully restored water relations post-flooding. This indicates that while recovery strategies differed, all genotypes achieved effective water balance restoration, an essential aspect of post-flooding recovery.

The morphological recovery patterns observed in this study further supports Hypothesis 2, demonstrating that the three genotypes employed distinct morphological adaptation strategies during recovery from flooding stress.

5.4 Implications for breeding flood-tolerant varieties

The distinct recovery patterns and mechanisms identified in this study have important implications for breeding flood-tolerant varieties of *Solanum aethiopicum* Shum. The rapid recovery of E11, despite its initially lower vigor, suggests that breeding efforts should focus on incorporating rapid recovery traits rather than solely selecting for vigorous growth under normal conditions.

The superior chlorophyll retention and biomass accumulation in E16 indicate that this genotype possesses valuable traits for maintaining productivity after flooding events. The intermediate recovery time of E16 (8.88 days), combined with its superior final biomass, suggests that moderate recovery speed coupled with efficient resource allocation may be optimal for yield stability in flood-prone environments.

The contrasting recovery strategies observed in the rapid visible recovery of E11 with fewer but larger leaves versus E15 and E16's slower visible recovery with numerous new leaves—suggest that multiple physiological pathways contribute to flooding resilience. Breeding programs could potentially combine these complementary traits to develop varieties with both rapid recovery and high productivity post-flooding.

The root development differences among genotypes highlight the importance of below-ground traits in flooding recovery. The longer roots in E16 likely contributed to its superior biomass accumulation, suggesting that root system architecture should be considered in breeding for flood tolerance. This aligns with findings by Bailey-Serres et al. (2012), who emphasized the role of root system plasticity in flood recovery.

Overall, this study demonstrates that different genotypes of *Solanum aethiopicum* Shum possess distinct and valuable traits for post-flooding recovery. Breeding programs should aim to pyramid these traits into new varieties that combine rapid recovery (from E11), high chlorophyll retention and new leaf production (from E15), and robust root development and biomass accumulation (from E16). Such varieties would be better equipped to maintain productivity in increasingly flood-prone agricultural landscapes, contributing to food security in the face of climate change.

CHAPTER SIX:

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of key findings

This study evaluated the post-flooding recovery potential and growth responses of three *Solanum aethiopicum* Shum genotypes (E11, E15, and E16) to identify flood-resilient traits for improving productivity in flood-prone areas. The key findings are:

Significant variations in recovery time were observed among genotypes, with E11 demonstrating the fastest recovery (5.21 days), E16 showing intermediate recovery (8.88 days), and E15 exhibiting the slowest recovery (14.46 days).

Genotypes employed distinct physiological recovery strategies, with E15 and E16 maintaining higher chlorophyll content throughout the recovery period, while E11 showed lower initial chlorophyll levels but greater improvement over time.

Morphological recovery patterns differed among genotypes, with E11 developing fewer but larger leaves, while E15 and E16 prioritized producing numerous new leaves.

Root development and biomass accumulation varied significantly, with E16 developing the longest roots (16.03 cm) and accumulating the highest biomass (48.67 g fresh weight, 7.17 g dry weight), followed by E15 and E11.

Despite differences in recovery strategies, all genotypes successfully restored water relations post-flooding, as evidenced by similar tissue water content percentages (84.28-88.33%).

Recovery potential was not necessarily correlated with initial plant vigor, as E11 demonstrated the fastest recovery despite having lower pre-flooding growth parameters.

Findings also suggest that *Solanum aethiopicum* Shum possesses genetic resources for flooding tolerance that could be valuable for breeding programs targeting flood-prone environments.

The results contradict the initial hypothesis in terms of the expected recovery rate range but confirm the existence of genotypic variation in flooding tolerance. This indicates that *Solanum aethiopicum* Shum may have evolved more effective adaptive mechanisms to flooding stress than previously recognized, positioning it as a potentially valuable crop for regions experiencing periodic flooding.

6.2 Conclusions

Solanum aethiopicum Shum possesses substantial genetic variability for flooding tolerance and recovery potential, with genotypes exhibiting different recovery times, physiological responses, and morphological adaptations following flooding stress.

Recovery from flooding stress in *Solanum aethiopicum* Shum involves multiple mechanisms, including restoration of photosynthetic capacity, regeneration of photosynthetic tissues, and root system development, with genotypes prioritizing these mechanisms differently.

Rapid visible recovery in E11, it does not necessarily correlate with superior biomass accumulation, as E16 accumulated the highest biomass despite its intermediate recovery time, suggesting that recovery speed alone is not indicative of productivity restoration.

The recovery potential of *Solanum aethiopicum* Shum genotypes appears to be governed by genotype-specific traits rather than general plant vigor, as evidenced by E11's rapid recovery despite its lower initial growth parameters.

Root system recovery plays a crucial role in overall plant recovery from flooding stress, as demonstrated by the association between root length and biomass accumulation in E16.

The observed recovery rates (5.21-14.46 days) and distinct physiological and morphological changes support both hypotheses of this study, confirming that *Solanum aethiopicum* Shum genotypes exhibit differential recovery rates and distinct adaptive responses to flooding stress.

6.3 Recommendations for farmers

In areas prone to short-duration flooding, farmers should prioritize growing genotype E11, which demonstrates rapid recovery from flooding stress. In regions with less frequent but potentially longer flooding events, genotype E16 may be more suitable due to its superior biomass accumulation post-flooding.

After flooding events, farmers should provide adequate nutrients, particularly nitrogen, to support recovery of chlorophyll content and leaf development. Special attention should be given to supporting root system recovery through gentle soil aeration if possible.

Farmers should implement improved drainage systems to minimize flood duration, as even flood-tolerant genotypes showed significant stress symptoms during extended flooding.

6.4 Recommendations for breeding programs

Breeding programs should focus on selecting for specific flood tolerance traits, including rapid recovery time (from E11), chlorophyll retention during flooding (from E16), robust root system development (from E16), and efficient new leaf production post-flooding (from E15).

6.5 Recommendations for future research

Determine the critical flooding duration thresholds for different genotypes beyond which recovery becomes compromised, providing valuable information for risk assessment in flood-prone areas.

Investigate biochemical adaptations, particularly carbohydrate metabolism and antioxidant systems, which contribute to enhanced recovery potential in flood-tolerant genotypes.

Extend research to include assessment of flowering and fruiting recovery post-flooding, as reproductive success is ultimately crucial for seed production and crop yield.

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APPENDIX

Budget

Items	Quantity	Amount
Potting bags	60	20,000
Nutrient amendments (NPK)	2kg	16,000
Measurement tools	1	1000
Transport		20,000
Soil	1 trip	150,000
Manure	7 bags	70,000
Fire wood	1 trip	450,000
Total		727,000

1	Genotype id	plant number	replication	plant height (cm)	number of leaves	visual score	stem diameter (cm)	chlorophyll 1	chlorophyll2	leaf length (cm)	leaf width (cm)	petiole length (cm)	canopy (cm)	new leaf count
2	E11.	1	1	29.9	7	5	6	18.9	18.8	16.9	12.5	3.7	34.2	6
3	E11.	2	1	34.1	9	5	7	36.4	48.3	16.7	13.1	4.4	34.6	11
4	E11.	3	1	27.2	7	5	5	18.7	19.7	15.6	12.4	4.5	33.5	4
5	E11.	4	1	26.4	7	4	7	24.6	26.5	11.5	8.5	3.4	26.9	13
6	E11.	5	1	37.5	10	5	6	24.3	25.8	15.1	11.6	4.1	33.1	12
7	E11.	6	1	31.7	7	5	5	23	25.1	13.4	11.2	4.3	33.2	3
8	E11.	7	1	36.2	8	4	7	34.3	30.4	19.4	12.9	5.4	32.1	8
9	E11.	8	1	35.6	8	5	6	22.2	26.9	16.1	10.9	3.6	31.9	10
10	E11.	9	1	34.9	9	5	6	30.4	24.2	17.2	14.5	5.3	34.6	10
11	E11.	10	1	27.6	6	5	5	20.5	17.6	13.3	10.9	3.5	26.6	7
12	E11.	1	2	48.5	9	5	7	33.5	25.5	17.1	13.6	5.3	35.9	6
13	E11.	2	2	40.9	9	5	6	27.5	29.5	17.2	15.1	4.4	35.7	4
14	E11.	3	2	36.1	8	5	6	26.8	30.1	18.6	15.3	4.2	36.1	10
15	E11.	4	2	42.6	8	5	7	27.7	29.6	16.7	13.7	4.6	31.9	3
16	E11.	5	2	37.5	15	5	6	28.5	46.7	20.4	16.1	4.6	40.1	17
17	E11.	6	2	49.5	10	5	7	38.1	37	14.4	10.6	3.1	30.5	14
18	E11.	7	2	38.6	8	5	6	23.7	23.5	13.3	11.4	4.2	29.1	3
19	E11.	8	2	34.2	10	5	7	36.8	34.8	15.4	11.2	3.2	31.4	13
20	E11.	9	2	35.9	8	5	6	28.2	26.1	15.8	13.9	4.1	35.6	14
21	E11.	10	2	41.5	8	5	7	36.6	28.7	16.9	14.4	3.6	41.3	12
22	E11.	1	3	26.7	8	4	5	19.4	30.4	13.4	9.9	3.2	26.2	10
23	E11.	2	3	25.4	9	5	6	31.1	31.3	9.3	7.9	2.2	23.8	10
24	E11.	3	3	38.8	7	4	8	19.3	26.3	11.2	9.5	3.9	33.1	7
25	E11.	4	3	59.1	10	4	8	21.2	22.9	10.4	7.1	1.9	31.4	6

Sheet1 Sheet2 Sheet3 Sheet4 Sheet5

Figure 9: Data sheet of the last week post flooding

	A	B	C	D	E	F	G
1	Gentype id	plant number	replication	root length (cm)	fresh weight (g)	dry weight (g)	Water content (%)
2	E11.	1	1	13.2	40	4	90
3	E11.	2	1	8.8	42	4	90.47619
4	E11.	1	2	23.4	50	3	94
5	E11.	2	2	13.4	37	9	75.67568
6	E11.	1	3	5.9	25	4	84
7	E11.	2	3	8.4	28	5	82.14286
8	E15.	1	1	13.4	50	4	92
9	E15.	2	1	19.1	32	5	84.375
10	E15.	1	2	12.2	36	4	88.88889
11	E15.	2	2	13.6	41	4	90.2439
12	E15.	1	3	12.8	45	6	86.66667
13	E15.	2	3	17.8	41	5	87.80488
14	E16.	1	1	22.5	46	5	89.13043
15	E16.	2	1	16.6	69	8	88.4058
16	E16.	1	2	14.3	56	6	89.28571
17	E16.	2	2	11.2	51	8	84.31373
18	E16.	1	3	13.9	27	6	77.77778
19	E16.	2	3	17.7	43	10	76.74419

Figure 10: Data sheet at the end of experiment

Figure 13: weighing 10kg of soil in the pot

Figure 12: arranging pots aside after weighing

Figure 11: sterilizing soil using steam

Figure 16: mixing soil with poultry manure

Figure 15: Transplanting seeding to pots

Figure 14: Carrying out data collection

Figure 19: state of plants post flooding.

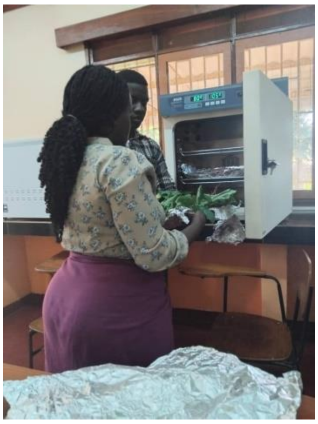

Figure 18: Placing plants in oven for dry weight

Figure 17: State of plants during flooding