EVALUATION OF SEED QUALITY IN THREE RELEASED VARIETIES OF SOLANUM AETHIOPICUM SHUM ACROSS SEASONS

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ABSTRACT

Solanum aethiopicum Shum presents differences in germination performance with a relatively low germination percentage of 0-25% and this is attributed to the relative response of different varieties to germination conditions caused by intraspecific factors such as genetics. With progression of generations over seasons, seeds vary in the stability levels of inheritance of superior traits for germination pointing out the difference in levels of seed quality for efficient crop establishment and growth. This research evaluated seed quality of *Solanum aethiopicum* Shum varieties E11, E15, and E16 over two seasons and the effect of germination synchrony on plant growth performance. This was objectively to check for stability of germination of the varieties with progression over seasons and establish how levels of germination synchrony influence plant establishment and growth.

The experiment was carried out in a screen house at Uganda Christian University, Mukono using a Completely Randomized Design, with three replicates for three varieties. Germination study was conducted in a healing chamber and germination metrics recorded were germination percentage, mean germination time, germination velocity index, and germination synchrony. Subsequent plant growth was conducted in a screen house and growth metrics studied were plant height, plant canopy, stem girth, leave dimensions, and petiole traits.

Results of the study indicated that germination performance varied across all varieties over seasons with p-value 0.229 for germination percentage, p-value 2.46 for Mean Germination Time, p-value 0.046 for Germination Velocity Index, and p-value 0.064 for Germination Synchrony at significance level of 5%. Furthermore, different levels of germination synchrony across the varieties had marginal to significant effects on plant growth performance where variety E11 expressed relatively stable genetic expression across seasons in its germination rates followed by varieties E15 and E16. Additionally, different germination synchrony levels exhibited variations in all plant growth parameters with exception of petiole length suggesting a strong influence of

germination synchrony on plant establishment other the germination velocity index on plant growth.

Declaration

I ECORA FAITH AKILE hereby declare that this dissertation is entirely my original work except where I have acknowledged references by other authors, and it has not been presented partially or wholly in any other institution for any award.

Signature: ecora faith akile

Date: 15th April, 2025

Approval

This is to certify that this dissertation has been submitted for examination with approval of my academic supervisor as a requirement for the award of a degree in Bachelor of Agricultural Science and Entrepreneurship at Uganda Christian University.

Signature: .... Date: 15/04/2025

Ms. MILDRED JULIAN NAKANWAGI

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List of Acronyms

AIV	African Indigenous Vegetables
AOSA	Association of Official Seed Analysts
ANOVA	Analysis of Variance
CRD	Completely Randomized Design
CUG	Coefficient of Uniformity of Germination
DNA	De-oxyribonucleic Acid
GP	Germination Percentage
GVI	Germination Velocity Index
GS	Germination Synchrony
ISTA	International Seed Testing Association
MGT	Mean Germination Time
SDG	Sustainable Development Goals

CHAPTER ONE

1.1 Background

Solanum aethiopicum Shum is a nutrient-rich horticultural crop belonging to the Solanaceae family (Buteme *et al.*, 2021). It is also referred to as scarlet eggplant or garden egg, said to have originated from tropical Africa (Plaza *et al.*, 2024) and evolved from *Solanum anguivi* (Godfrey *et al.*, 2017). It is one of the four sub-groups of *Solanum aethiopicum* on morphological variations which include gilo, kumba, aculeatum, and Shum, cultivated for their leaves and fruits for consumption and ornamental purposes for the aculeatum group (Buteme *et al.*, 2021). The Shum group locally known as 'nakati' in Uganda is a common highly nutritious African Indigenous Vegetable, (AIV) cultivated for its leaves (Kabod *et al.*, 2018). However, the vegetable has received less attention (Nakyewa *et al.*, 2021), and there is limited knowledge about the crop among researchers (Botey *et al.*, 2019; Han *et al.*, 2021) and so to explore this loophole, this study focuses on evaluating seed quality of the African vegetable considering seed germination as an indicator. Seed germination is influenced by a combination of genetic traits and environmental conditions, essential for understanding plant adaptation, population dynamics, and cultivation success (Maleki *et al.*, 2023). As shown by Ghaleb *et al.* (2022), factors such as germinability and rate can vary within seed populations across generations, reflecting adaptive mechanisms or selective pressures in response to cultivation practices and environmental shifts. This aligns with Govindaraju and Dancik's (2021) findings, which highlight that stability indices in germination can differ significantly across developmental stages, stressing the importance of evaluating genetic stability over time to check for heritability levels over the seasons (Sales *et al.*, 2013). The African eggplant is known to have a germination period of 5-9 or even more days from sowing (Lozano *et al.*, 2022) which accounts for possibility in difference of rates of germination with a germination percentage range of 0%-25% (Botey et al., 2021) indicating variation in seed quality among varieties across seasons

Synchrony, or the uniform timing and simultaneous germination among seeds (Botey et al., 2021), can impact plant establishment, competition, and resilience to environmental stresses. Across generations and over seasons, heritability is influenced by mendelian & non-mendelian genetics (Achrem *et al.*, 2023; Mittelsten Scheid, 2022; Strome *et al.*, 2024)(Achrem et al., 2023; Mittelsten Scheid, 2022; Strome et al., 2024). However, levels of phenotypic expression vary with progression of generations due to effects of inbreeding depression and DNA methylation(Walter *et al.*, 2023). To further contribute to the understanding of synchrony in the three cultivated species based on seed quality, this research will explore whether this trait remains consistent or adapts based on environmental and genetic influences, and the extent of this variation across seasons for the different varieties highlighting the potential implications for breeding, commercial bulking, and cultivation practices.

As shown by Ghaleb *et al.* (2022), factors such as germinability and rate can vary within seed populations across generations, reflecting adaptive mechanisms or selective pressures in response to cultivation practices and environmental shifts and so the purpose of studying different seasons points out the stability for inheritance of desirable traits by the relative varieties over the seasons to identify heritability levels. Therefore, germination synchrony explains dormancy patterns and seed adaptation to the environment and it is relatively expressed over seasons due to heritable fitness traits that are relative to individuals and varieties (Walter *et al.*, 2023)

1.2 Statement of the problem

Solanum aethiopicum Shum presents differences in seed germination days (Han *et al.*, 2021) over a range of five (5) or more days that is 5-9 days from sowing and a germination percentage range 0-25% (Botey et al., 2022) which is wide enough to optimize varieties with highest germinability and synchrony over seasons. Within a seed's potential, germination stability indices can differ across developmental stages (Govindaraju & Dancik, 2021). During germination, seed adaptations to germination conditions in the environment differ in occurrence of processes of imbibition, enzyme activation, elongation of the hypocotyl, and seed coat rupture. The difference in germination timing categorizes the Shum plant population into early and late germinators depending on the timing of seedling emergence. This, subsequently affects overall plant fitness, health and yield of the population basing on the stability levels of inheritance of different varieties across generations for plant breeding programs and bulking for commercial purposes aligning with Sustainable Development Goals 1 and 2 (FAO, 2021)

1.3 Objectives

To assess *Solanum aethiopicum* Shum varieties most suitable for early germination and uniformity across generations

1.3.1 Specific Objectives

1. To investigate the germination rate of the three released varieties of *Solanum aethiopicum* Shum under optimum conditions across seasons (stability)
2. To determine subsequent plant growth at different germination synchrony levels across the selected varieties

1.4 Research hypotheses

- There is a difference in levels of germination synchrony of the three released varieties of *S.aethiopicum* Shum across seasons
- There is a difference in subsequent plant growth at different germination synchrony levels across the selected varieties

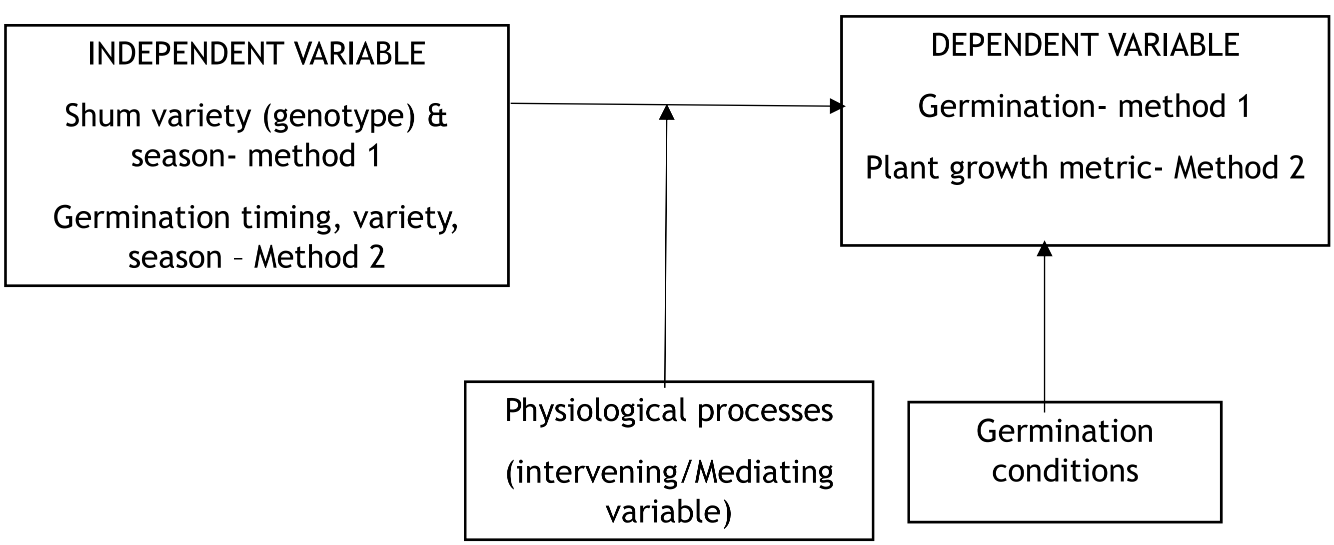
1.5 Justification

Across inbred generations over seasons, stability is obtained due to increased homozygosity from a reduced gene pool from inheritance of strong genetic components (Walter *et al.*, 2023). This results into a consistency in the gene frequency thus genetic uniformity where constant alleles for desirable traits are identified, providing an insight into breeding practices through reliable data for seed viability and vigor, and bulking seed production systems for seed quality based on performance across seasons (Kebede *et al.*, 2016). According to Gramazio *et al.*, 2017, enhancing the seed system for scarlet eggplant aligns with the global efforts through the Sustainable Development Goals, (SDG) to develop climate- smart and resilient vegetable varieties. Through this study, researchers can determine the extent to which synchrony is maintained over planting seasons, suggesting a strong genetic relative for the three varieties. Uniformity in the seed bank also facilitates agronomic efficiency through its direct impact on planting density, plant competition, and overall crop yield facilitated by uniform growth and better nutrient uptake. Uniform crop establishment and maturity, makes cultivation less difficult for the local farmers in terms of management to obtain consistent, reliable crop production, and steady income generation (Bewley & Bradford, 1994).

1.6 Significance

With rising global concerns about climate variability, seed quality evaluation through germination synchrony is a selectively adaptive trait which stabilizes crop establishment under variable climatic conditions (Merrick *et al.*, 2020). This is especially relevant to the Sub- Saharan countries with unpredictable rains and temperature shifts. By analyzing the traits in the different varieties for seed quality, genetic diversity within the species is evaluated, providing ground for future breeding efforts to strengthen nutrition and food security (Grubben and Denton, 2004). Evaluating seed quality traits of different Shum varieties especially germination synchrony, to be utilized by commercial producers for bulking reduces cases of replanting and excessive seed usage which contributes to resource efficiency and minimizes agricultural wastage thus aligning with sustainable agriculture goals that emphasize responsible use of inputs to protect environmental resources without compromising long- term productivity (Bradford *et al.*, 2017). Identifying seed quality stability traits of *Solanum aethiopicum* Shum also holds importance in achieving uniform seedling emergence and establishment thereby enhancing agronomic efficiency by optimizing agricultural productivity and obtaining consistent yields especially in resource-constrained farming systems (Bradford *et al.*, 2017).

1.7 Conceptual frame work



CHAPTER TWO

2.0 Literature review

2.1 Taxonomy of *Solanum aethiopicum* Shum

Solanum aethiopicum is a leafy vegetable that evolved from the wild *Solanum anguivi*, with the taxonomic classification of kingdom Plantae, Phylum Tracheophyta, Class Magnoliopsida, Order Solanales, Family Solanaceae, Genus Solanum, and Species *aethiopicum*. Shum is one of the four sub- groups of *S. aethiopicum* alongside other groups of gilo, kumba, and aculetum (Jäger et al., 2023)

2.2 Botany and agronomy of *S. aethipicum* Shum

It is often grown as an annual crop, with its leaves being harvested for 2 or more seasons. However, it is a perennial plant with more or less woody and much branched stems. Its propagation is by seed, with germination taking averagely 5- 9 days (Botey *et al*., 2022) and transplanting of seedlings to the field is done 30- 35 days from the day of sowing when plants have attained a height of 15- 20cm with 5- 7 leaves. Seedlings grow at a fast rate and flowering starts at 40- 100 days from sowing and first flowers are concurrently initiated with branching and the production of younger leaves (Prakash & Sharma, 2017; Bragard et al., 2021).

It can be cultivated in home gardens and grown commercially for sale in local markets. With a growing season of at least three months, the plant does best in areas with annual day time temperatures ranging between 20- 30^{0}C and a mean annual rainfall of 1200mm- 1600mm but tolerant to lower amounts of 800mm. Moderately fertile, well-drained soils that are exposed to sunlight are best for the plant with PH range of 5.5- 7 is best, while ensuring moderate nitrogen levels to optimize leaf yield. Where irrigation is involved, yield ranges between 12- 20t/ha with improved cultivars yielding 50- 80t/ha under favorable conditions. Shum cultivars under good management produce up to 75 leaf bundles of 30kg each implying a yield potential of 225t/ha (Buteme et al., 2021). This enables for optimization of varieties with highest seed quality in terms of germination timing, percentage, and synchrony to achieve that yield potential. (Bragard et al., 2021)

2.3 Challenges facing production of *S.aethiopicum* Shum

Globally, production of Shum is faced with a challenge of heterogeneity of phenotypic responses, which explains the lack of stability, as it interferes with uniform plant response to water stress and it is one of the major challenges to Shum productivity (Tumuhimbise et al., 2022). This affects responses such as the reduction in leaf elongation and impacts stomatal closure, thereby reducing the nutrient value of stressed plants and lowering their market value (Gabriel, 2013; Kiwuka et al., 2020) Africa is experiencing climate variations where the normal dry and wet seasons are currently shifting to being wetter and hotter than before, posing challenges to plant resilience to water loss (Mubiru et al., 2018). This has created a gap that causes yield losses, hence prompting the need for optimization of well-performing Shum varieties with early, rapid, and synchronized germination to improve field management practices uniformly across all established plants (Bragard et al., 2021). Locally, in Uganda, farmers and gender-based preferences for Nakati varieties vary depending on the yield experienced in the major Nakati-growing districts, namely Mukono, Wakiso, and Luweero (Nakyewa et al., 2021) The identification of the variety with the highest synchrony has been shown to produce more yield compared to others, contributing to the livelihoods of an estimated 400,000 people in Uganda (Nakyewa et al., 2021;Nsubuga et al., 2014). Nonetheless, erratic germination behavior and poor seedling establishment are also common challenges faced by farmers, often due to reliance on saved and recycled seeds (Botey *et al*., 2019, 2021). These issues highlight the importance of understanding seed germination dynamics and developing varieties with desirable germination traits like synchronization.

2.4 Importance of seed quality

Seed quality, as a vital aspect of successful crop production, includes physiological aspects such as germination capacity, vigor, viability, and physical aspects of purity and health (ElMary et al., 2019; Turner et al., 2020). The seed quality assessment is vital for high yield potential as well as encouraging effective seed usage in agricultural systems (Dias et al., 2023). Additionally, seed health as part of seed quality is significant for vigor longevity, and its ability to minimize diseases that could arise during propagation (Saldanha et al., 2020) and various germination tests can be conducted alongside other technological advancements to evaluate seed quality so as to maintain seed integrity throughout the production and storage cycles (Rego et al., 2020; Sundareswaran et al., 2023)

2.5 Germination behavior over seasons

As germination stability ensures the predictability of germination traits across different planting cycles, it is influenced by genetic and environmental factors. Studies have revealed various key insights such as intra-varietal variability where research shows that S. *aethiopicum* exhibits genetic diversity affecting germination rates (Buteme *et al.*, 2021). Differences in floral and phenological traits among varieties contribute to variability in seed vigor and synchrony.

While there is a lack of specific research on the germination rate and stability of S. *aethiopicum* Shum varieties across generations, studies on related *Solanum* species provide valuable insights (Botey *et al.*, 2021). Physiological dormancy, observed in *Solanum melongena* and *Solanum torvum*, can also contribute to low germination percentages (Botey *et al.*, 2017) and this may be influenced by the maturity stage of the fruit at harvest and the extraction process (Botey *et al.*, 2017). Genetic factors such as seed size and the rate and duration of seed filling, can impact the accumulation of food reserves within the seed, (Silva *et al.*, 2015; Santos *et al.*, 2020; Botey, 2022) which in turn, influences germination and initial seedling growth.

2.6 Impact of germination timing on growth

The timing of germination plays a pivotal role in determining early-stage plant vigor and overall development in factors like competition for resources to impact seedling survival and growth (Sales et al.,2013). Related studies reveal that early germinating seeds of Solanaceae, including S. *melongena*, outperformed late germination in plant fitness such as root and shoot development (Margenot *et al.*, 2016; Verdu, M., Travest, A., 2005). Similar effects were observed in S. *aethiopicum*, where early germinators had higher biomass accumulation. Physiologically, early germination positively impacted nutrient absorption and stress resilience, especially under optimized fertilization regimes (Margenot *et al.,* 2016). As per crop establishment, early and uniform germination ensured synchronized growth phases, reducing competition for resources (Buteme *et al.,* 2021). While maintaining all environmental factors constant in a screen house, the study aims to evaluate germination characteristics across seasons for the three varieties so as to identify the variety with superior genetic strength of desirable traits of early and synchronous germination for positive impact on subsequent growth and potentially higher- yielding plants.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Methodology 1

Evaluating germination rates in *Solanum aethiopicum* Shum

3.1.1 Area of study

The germination studies were conducted in the screen house at Uganda Christian University in Mukono district, located in the central part of Uganda approximately 27km East of Kampala. It lies at an altitude of 1158-1219m above sea level. The district receives two wet seasons with an annual rainfall ranging between 1100 and 1400mm. Temperatures experienced range between 21^{0}C and 29^{0}C with coordinates $00^{0}20'$N $32^{0}45'$E. This experiment ran from January 2024 to March 2025 with day screen house temperatures ranging between 18^{0}C to 42^{0}C

3.1.2 Study material

Seeds for the three released varieties of *Solanum aethiopicum* Shum, 148 (E11), 137 (E15) & 184 (E16) were used. These were obtained from the faculty of Agricultural Sciences seed bank, and seeds used were selfed- seeds (hybrids). Variety E11 is characterized with green stems, green leaves and leaf veins with generally whole leaf margins, variety E15 has green- purple stems, green leaf veins, and moderately serrated leaf margins, and E16 is purple stemmed, has green leaves with purple-green leaf veins, and has serrated leaf margins

3.1.3 Experimental Design

Using Complete Randomized Design, (CRD), 100 seeds for each variety were planted in planting trays with 3 replicates for each variety for the germination study (Steel & Torrie, 1980), ensuring sufficient sample size for statistical analysis(Ranal & De Santana, 2006). Each replicate was tagged and labeled with information about the variety, date of planting, and replicate number. The substrate used was steam-sterilized soil mixed with well-decomposed poultry manure in a ratio of 3:1 for the *S. aethiopicum* Shum seeds. The experiment was conducted in a healing chamber with controlled temperature and light conditions with average 20-45% humidity and 20-49^{0}C temperature as per guidelines for germination studies (Analysts & Seed, 2014)

3.1.4 Data collection

Visual observation for emergence of seedlings above the soil that is, the plumule or hypocotyl was considered to record for germination. Germination was monitored at an interval of every 24 hours (daily) and the number of germinated seeds at each observation time in the seed bed was recorded in a physical data sheet and later entered into Microsoft excel for accuracy (Finch-savage & Leubner-metzger, 2006).

The independent variables were the Shum varieties (148, 137, & 184) and the season while the dependent variables were the germination characteristics in terms of speed and overall number of germinated seeds among the total number sown. The control variables were the germination conditions as temperature, moisture, and light, and the mediating variables were the germination physiological processes as imbibition, activation of hormones, and elongation of the hypocotyl coupled with seed coat rupture (*Bewley et al 2013*)

3.1.5 Data Analysis

The germination rate was calculated in terms of final germination percentage, germination velocity index, GVI and mean germination time, GMT for each variety and season. This followed established formulae for germination assessment (Scott *et al.*, 1984)

Germination percentage= $\frac{No.of\ germinated\ seeds}{Total\ number\ of\ seeds\ planted} \times 100$

Germination Mean Time, GMT= $\frac{\Sigma(n \times d)}{N}$, where *n*- number of seeds that germinated on each day, *d*- number of days from the start of the experiment, and *N*- the total number of seeds that germinated by the end of the experiment

Germination velocity index, GVI= $\Sigma \frac{N1}{D1} + \frac{N2}{D2} \dots \dots + \frac{Nn}{Dn}$

Germination synchrony was calculated using the coefficient of uniformity of germination (CUG) (Primack, 1980).

CUG= $\frac{\sum_{i=1}^{k} Ni}{\sum_{i=1}^{k}(T-T_I)^2\, N_i}$, Where T is the mean germination time, T_i is the time from the start of the experiment to the *i*th interval, N_i is the number of seeds germinated in the *i*th time interval (not accumulated), and *k* is the total number of time intervals. Statistical analysis was conducted using Analysis of Variance, ANOVA, t-tests to compare germination rates and synchrony among varieties and generations (Gomez & Wiley, 1984). ANOVA tests were conducted to analyze the data so as to determine if there were significant differences in germination rates among the African eggplant varieties and generations.

3.2 Methodology 2

Comparing effects of germination synchrony on crop growth in *Solanum aethiopicum* Shum

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3.2.1 Layout

Loam soil was mixed with well decomposed poultry manure in a ratio of 3:1 and sterilized using steam, as the substrate. Well steam sterilized soil was then packed in polypots weighing 10kg per pot using a weighing scale and the pots were arranged in the screenhouse using a block design of 15 pots per block with three replicates. After a week of allowing the soil to cool and watering in preparation for planting, 15 seedlings for each variety were transplanted into well tagged pots. Tags carried information about the variety, replicate, and date of transplanting. Spacing within sub plots was 45cm by 15cm for 15 plants per plot, and 45cm between plots of replicates. Agronomic practices such as regular watering, weeding, fertilizer application, and pest and disease control were carried out, while controlled light, humidity, and temperature conditions were monitored in the screen house (AOSA, 1993)

3.2.2 Layout

N1- 148							
Week 1	Week 2	Space between blocks 45cm	Week 1	Week 2	Space between blocks	Week 1	Week 2
15 plants	15 plants						
@3×5 pots							
45×15cm spacing							
N2- 137							
Week 1	Week 2	Space between blocks 45cm	Week 1	Week 2	Space between blocks	Week 1	Week 2
N3- 184							
Week 1	Week 2	Space between blocks 45cm	Week 1	Week 2	Space between blocks	Week 1	Week 2

1- Variety 148
2- Variety 137
3- Variety 184
4- Control variety

3.2.3 Data collection

From fifteen (15) seedlings transplanted, ten (10) plants were randomly selected for data collection on the growth parameters, ensuring unbiased sampling (Steel & Torries, 1980). Selected 10 plants were tagged using threads of different colors and data was collected once every week on 10 plants using materials such as rulers, Vanier calipers, pencils and hard copy data sheets. Data was collected on parameters such as plant height, plant canopy, stem girth, number of leaves, leaf length, and leaf width as standard indicators of plant growth and health (Ranal & De Santana, 2006)

The independent variables were germination synchrony levels, Shum varieties (148, 138 & 184), and the seasons (1 & 2). The dependent variables were the subsequent plant growth metrics as plant height, plant canopy, stem girth, number of leaves, leaf length, leaf width, biomass analysis of fresh weight and dry weight. The control variables were the germination conditions as temperature, moisture, and light, and the mediating variables were the germination physiological processes as imbibition, activation of hormones, and hypocotyl elongation coupled with seed coat rupture (*Bewley et Al 2013*)

3.2.4 Data analysis

Statistical data analysis was by conducting ANOVA and t-tests to compare growth parameters between levels of germination synchrony of each variety and season, as appropriate tools for examining variance and significance in plant studies (Gomez & Wiley, 1984). Analyzed data was used to determine if germination synchrony provided a significant advantage for subsequent growth in S. *aethiopicum* and the implications of the findings were discussed for plant breeders, commercial producers, and farmers, emphasizing the importance of selecting varieties with high germination synchrony and early germination rates.

CHAPTER 4

This chapter comprises of results of the study and their interpretation for germination tests and the subsequent plant growth influenced by germination synchrony. Four parameters were examined for germination performance for three varieties (E11, E15, AND E16) across 2 seasons. Data analysis conducted presented differences in interaction between seasons and varieties for each germination test and six parameters were assessed for subsequent plant growth.

4.1 Germination percentage

The proportion of seeds that successfully germinate under favorable conditions, usually expressed in percentage is the germination percentage. The data in the table shows germination percentages for the three varieties, E11, E15, and E16 tested in two different seasons, 1 and 2 with their Least Significant Difference, LSD groups that is, "a", "b", and "c" to illustrate the significant difference between groups. Germination percentage groups with similar LSD groups show no significant difference while differences in LSD groups indicate significant differences in the germination percentage. Season and genotype both demonstrated significant effects with no significant interaction between them at $p<0.05$. Variety E11 consistently showed higher germination percentage across both seasons with a higher increase in season 2 (87.7%). Varieties E11 and E15 performed with more moderate germination percentages, with E15 performing better in season 2 and both showing lowest values in season 1.

Table 1: germination percentage for seasons across varieties

season	variety	Mean Germination Percentage
2	E11	87.67 ± 2.082^{a}
1	E11	82.33 ± 2.082^{b}
2	E15	81.00 ± 1.000^{b}
2	E16	77.67 ± 1.528^{c}
1	E15	76.67 ± 0.577^{c}
1	E16	76.00 ± 2.646^{c}
Variety×Season p-value 0.2287		

Source	df	Sum sq	Mean sq	F value	P-value
Season	1	64.22	64.22	19.931	0.001
Variety	2	217.44	108.72	33.741	1.18e- 10
Season: genotype	2	10.78	5.39	1.672	0.2287
residuals	12	38.67	3.22		

4.2 Mean germination time

The average time, usually in days, taken for seeds to germinate is the mean germination time. Lower mean germination time values reflect faster speed and uniformity of germination as opposed to higher values of mean germination time. Faster germination is desirable in subsequent crop establishment and growth. There was no significant difference in interaction between season and genotype for Mean Germination Time. Variety E11 in season 1 had the longest germination time (8.41 days), indicating slowest germination. However, Variety E15 had consistently fast germination across both seasons (7.34- 7.36 days), indicating greater stability in germination traits across seasons

Table 2: Mean Germination Time for seasons across varieties

Season	Variety	Mean Germination Time
1	E11	8.410000 ± 0.01^{a}
2	E11	7.830000 ± 0.04^{b}
1	E16	7.520000 ± 0.01^{c}
2	E16	7.400000 ± 0.12^{cd}
2	E15	7.360000 ± 0.09^{d}
1	E15	$7.343333 \pm 0.08d^{d}$

Source	df	Sum sq	Mean sq	F value	P- value

Season	1	0.234	0.234	46.49	1.85e-05
Variety	2	2.075	1.038	206.62	5.05e-10
Season: Variety	2	0.293	0.147	29.18	2.46e-05
Residuals	12	0.060	0.005		

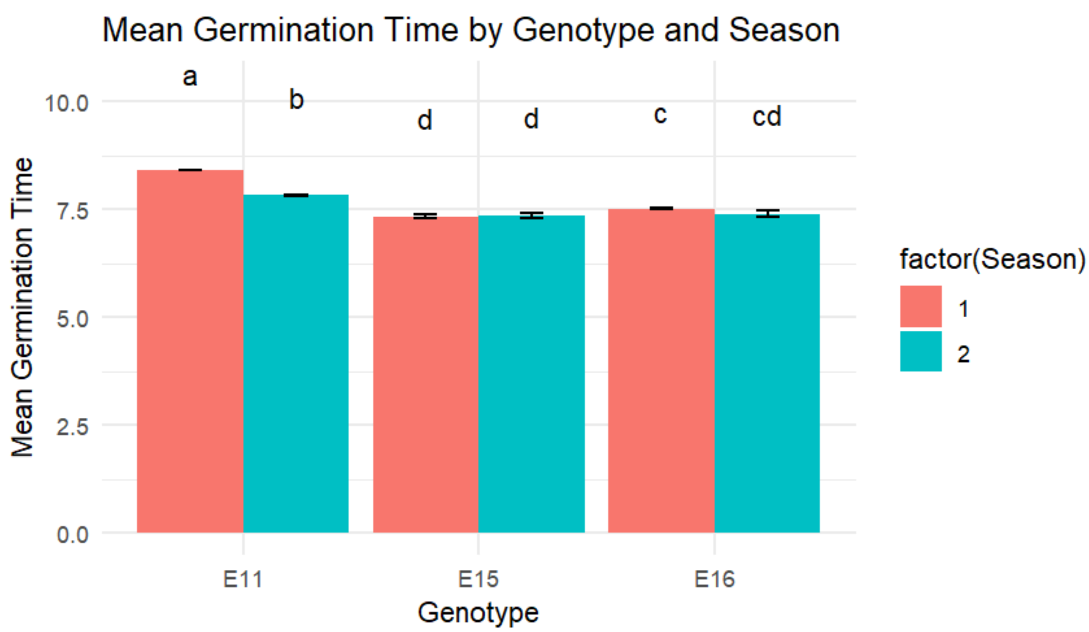

Figure 1: Mean Germination Time by Genotype and Season

4.3 Germination velocity index

Germination velocity index, GVI measures how quickly and vigorously seeds germinate over time where higher GVI values indicate a faster and more uniform germination providing a useful insight of seed vigor and quality to select high performing varieties across seasons over less performing varieties for farming and breeding purposes of superior traits. There was significant difference in interaction between season and variety at $p<0.05$ with p-value for the variety×Season of 0.0046. Variety E11 demonstrated differences between seasons with a low velocity in season 1 and high velocity in season 2. E15 had a consistently high germination velocity index in both seasons, indicating a more stable germination performance across seasons

Table 3: Germination Velocity Index for seasons across varieties

Season	Variety	Germination Velocity index
2	E11	11.73000 ± 0.255[a]
2	E15	11.71333 ± 0.255[a]
1	E15	11.34333 ± 0.191[ab]
2	E16	11.09667 ± 0.133[b]
1	E16	10.91000 ± 0.44[b]
1	E11	10.37333 ± 0.249[c]

Source	df	Sum sq	Mean sq	F value	P- value
Season	1	1.831	1.831	26.798	0.0002
Variety	2	1.010	0.505	7.396	0.0080
Season: variety	2	1.188	0.594	8.696	0.0046
residuals	12	0.819	0.0083		

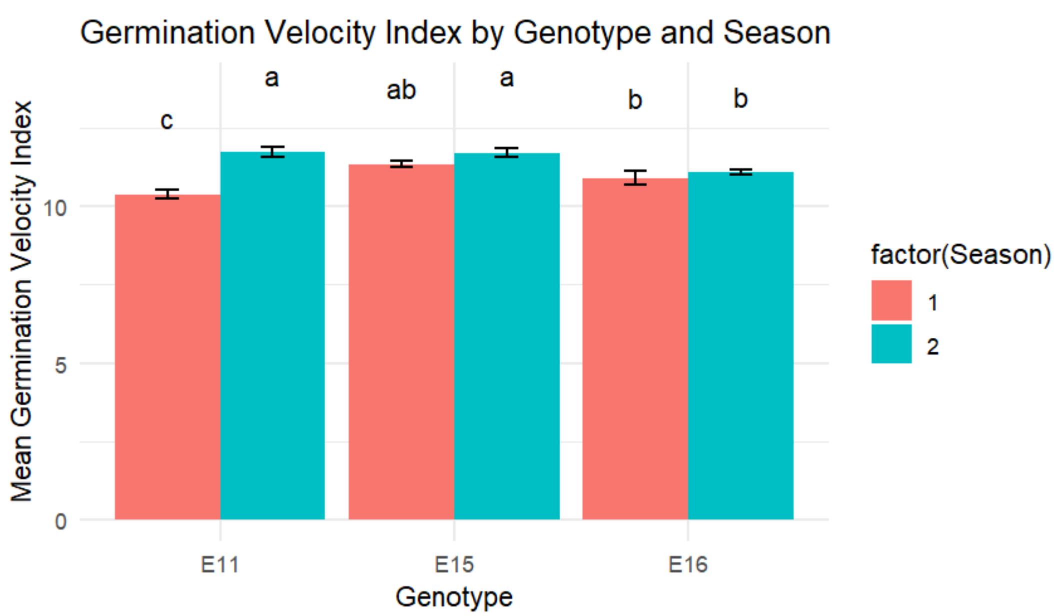

Figure 2: Germination Velocity Index by genotype and Season

4.4 Germination synchrony

The simultaneous germination or the degree to which seeds in a lot germinate at the same time reflecting uniformity, is referred to as germination synchrony derived from the calculation for coefficient of germination. Higher synchrony values mean that more seeds in the lot germinate more uniformly, which is often preferred for even seedling growth while lower synchrony values translate scattered and irregular germination timing. Germination synchrony values range from 0 to 1, with 1 illustrating perfect synchrony of all seeds germinating together. There was a significant difference in interaction between variety and season. Season 2 had higher synchrony values across all varieties, illustrating more uniform germination. E15 in season 2 achieved the highest synchrony (0.177), while all varieties in season 1 showed lower synchrony values. At p-value of 0.0635, there was a significant interaction between season and variety to the effect of germination synchrony level

Table 4: Germination Synchrony for seasons across varieties

Season	Variety	Germination synchrony
2	E15	0.1766667 ± 0.003^{a}
2	E16	0.1700000 ± 0.05^{ab}
2	E11	0.1600000 ± 0.00^{b}
1	E15	0.1433333 ± 0.003^{c}
1	E11	0.1400000 ± 0.00^{c}
1	E16	0.1333333 ± 0.003^{c}
Variety×Season p-value 0.0635		

Source	df	Sum sq	Mean sq	F value	P- value
Season	1	0.0041	0.0041	121.500	1.34e-07
Variety	2	0.0003	0.0002	5.167	0.0241
Season: variety	2	0.0002	0.0001	3.500	0.0635
Residuals	12	0.0004	0.00003		

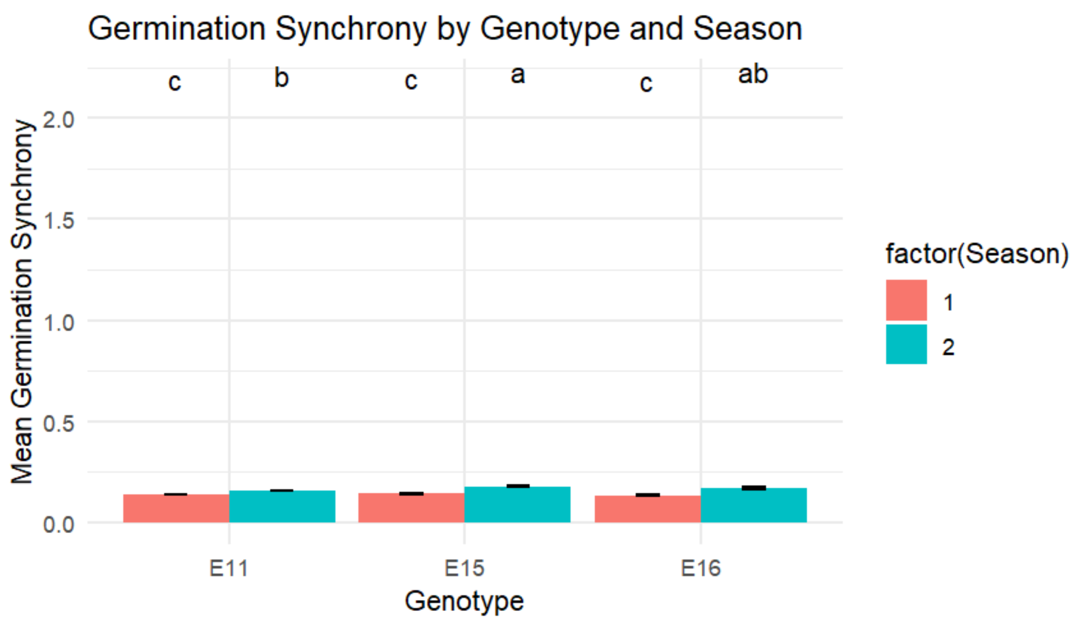

Figure 3: Germination Synchrony by Genotype and Season

OBJECTIVE 2

4.5 Plant growth performance by variety and germination synchrony level

The length at which a plant grows, usually measured in centimeters can be influenced by its genotype that is, variety and its early- stage vigor following the level of uniform germination. Taller plants indicate better seedling vigor and growth which offer competitive advantage in the crop population. The data in the table and graph present the relationships between the Shum varieties E11, E15, and E16 and germination synchrony levels with the effect on plant height, and a graphical representation to visualize plant height by variety and germination. Plant canopy refers to the above ground spread of the plant by measuring the diameter. Larger canopies indicate better vegetative growth with more leaf area thus a higher photosynthetic capacity beneficial for growth performance. Canopy development can be influenced by the variety (genetic potential) and germination vigor and uniformity which influence early growth. Variety E11 was observed to have the widest canopy at synchrony of 0.14 followed by E15 at synchrony of 0.15. E16 with the highest synchrony of 0.15 had the smallest canopy suggesting that while synchrony is beneficial, other factors such as genetics contribute to canopy development as moderate synchrony levels had optimal canopy formation

The thickness of a plant's main stem is the stem girth serving as an indicator of structural strength, nutrient transport capacity of the plant, and overall plant robustness. Thicker stems can support better plant performance by nutrient flow and withstanding environmental stresses as compared to thinner plant stems. Variety E15 produced the thickest stems at synchrony level of 0.14 suggesting better vegetative growth with significance difference. E16 demonstrated thinner stems under low synchrony levels, compromising stability levels while E11 produced plants with thin stems under 0.14 germination synchrony. The number of leaves of a plant indicates the vegetative growth of the plant. A larger number of leaves generally indicates higher photosynthetic capacity supporting better plant growth performance as compared to plants with fewer leaves. Germination synchrony affects leaf development through early seedlings and the genetic potential of the plant. Variety E15 produced the highest number of leaves followed closely by E16 and E11 had the lowest leaf count despite leading in plant height and canopy size

Leaf length is the measurement from the base of the leaf at attachment with the petiole to the tip of the leaf. It reflects a plant's growth and elongation capacity which presents the photosynthetic capacity for better energy production and growth. Germination synchrony affects leaf elongation alongside the genetics of the plant varieties. The measurement across the broadest part of the leaf is the leaf width and it presents a surface for photosynthetic activity of the plant. Broader leaves capture more sunlight implying higher photosynthesis rates for biomass production and growth. Unlike on mature leaves, germination synchrony may affect early leaf development though the effects of leaf width may be variety-dependent. For the result on leaf dimensions, variety E11 produced the longest and widest leaves, providing strong photosynthetic potential under moderate synchrony conditions of 0.14. Both E15 and E16 had shorter and narrower leaves at high and low synchrony of 0.13 and 0.15.

The petiole length is the measurement of the stalk that attaches the leaf blade to the plant stem before branching at the seedling stage. It influences the positioning of the leaf to capture light for photosynthetic efficiency and airflow around the leaves for respiration. Aside from how uniformly seeds germinate, germination synchrony may indirectly affect petiole growth through its effect on early seedling development. No significant differences were observed in the petiole length across all varieties, suggesting that germination synchrony has minimal impact on this trait.

Table 5: Plant growth parameters by germination synchrony and variety

Variety	Synchrony	Plant height	Plant canopy	Stem girth	Number of leaves	Leaf length	Leaf width	Petiole length
E11	0.14	13.19^{a}	30.19^{a}	5.84^{a}	19.78^{a}	13.56^{a}	11.11^{a}	3.92^{a}
E15	0.15	10.59^{b}	28.78^{a}	5.10^{b}	18.70^{a}	11.74^{b}	9.97^{ab}	3.77^{a}
E15	0.14	10.24^{b}	28.42^{ab}	5.00^{b}	18.30^{a}	11.71^{b}	9.75^{b}	3.49^{a}
E16	0.13	8.93^{b}	28.35^{ab}	4.73^{b}	17.95^{a}	11.70^{b}	9.65^{b}	3.43^{a}
E16	0.14	8.76^{b}	24.99^{b}	4.43^{b}	14.02^{b}	10.91^{b}	9.06^{b}	3.39^{a}

	Source	df	Sum sq	Mean sq	F value	P- value
Plant height	Variety	2	1156	578.0	19.847	6.75e-09
	Germination synchrony	2	4	2.1	0.071	0.932
	residuals	355	10338	29.1		
Plant canopy	Variety	2	525	262.35	3.021	0.050
	Germination synchrony	2	304	151.88	1.749	0.175
	residuals	355	30829	86.84		
Stem girth	Variety	2	12.7	6.358	1.267	0.283
	Germination synchrony	2	55.2	27.610	5.502	0.004
	residuals	355	1781.4	5.018		

number of leaves	Variety	2	1863	931.3	10.184	5e-05
	Germination synchrony	2	93	46.5	0.509	0.602
	residuals	355	32465	91.5		
Leaf length	Variety	2	319	159.53	7.916	0.0004
	Germination synchrony	2	17	8.69	0.431	0.6501
	residuals	355	7154	20.15		
Leaf width	Variety	2	181	90.29	6.345	0.002
	Germination synchrony	2	10	5.23	0.367	0.693
	residuals	355	5051	14.23		
Petiole length	Variety	2	12.4	6.178	1.747	0.176
	Germination synchrony	2	3.9	1.940	0.549	0.578
	residuals	355	1255.3	3.536		

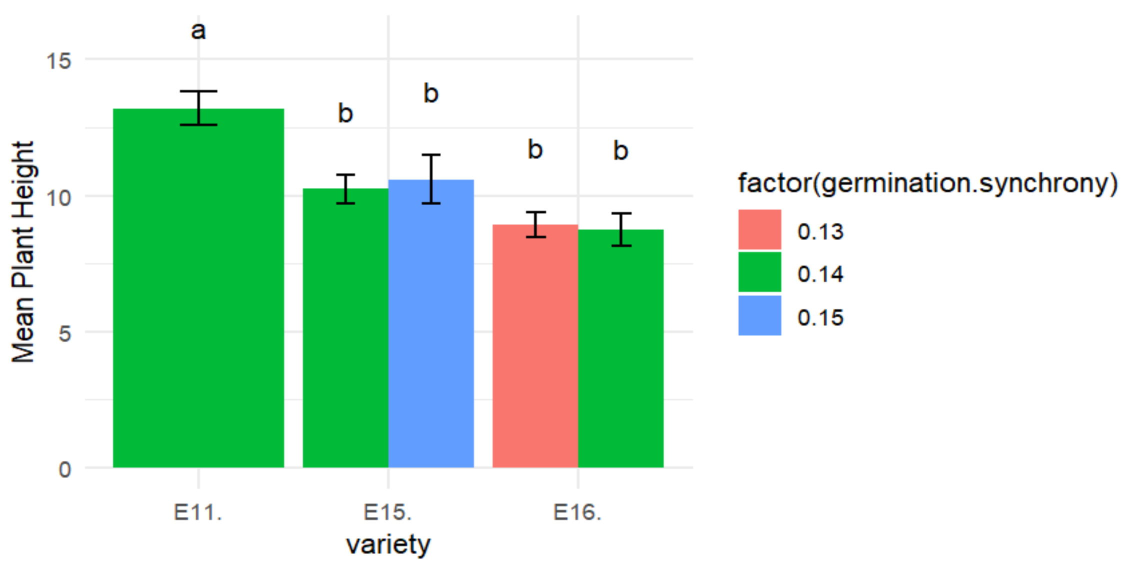

Figure 4: Plant height by Variety and Germination synchrony

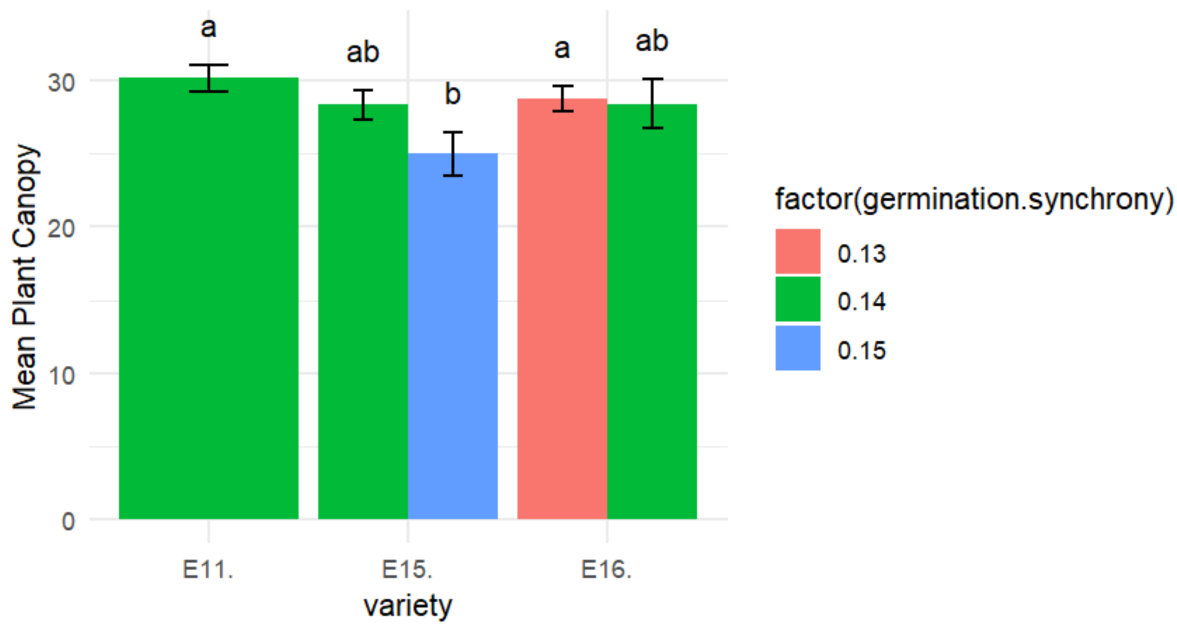

Figure 5: Plant canopy by Variety and Germination Synchrony

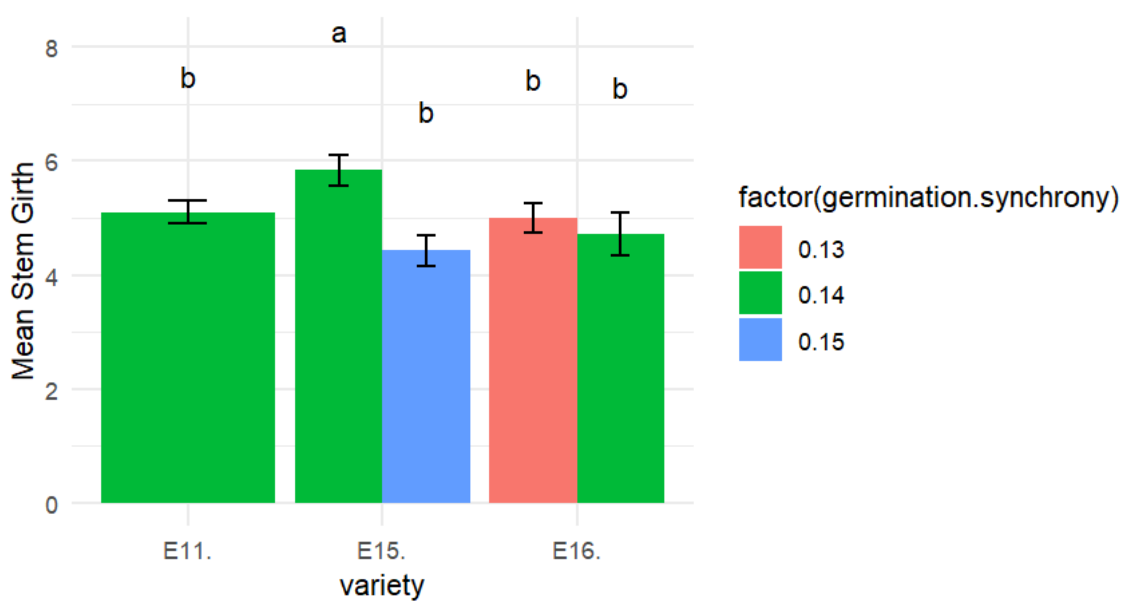

Figure 6: Stem girth by Variety and Germination synchrony

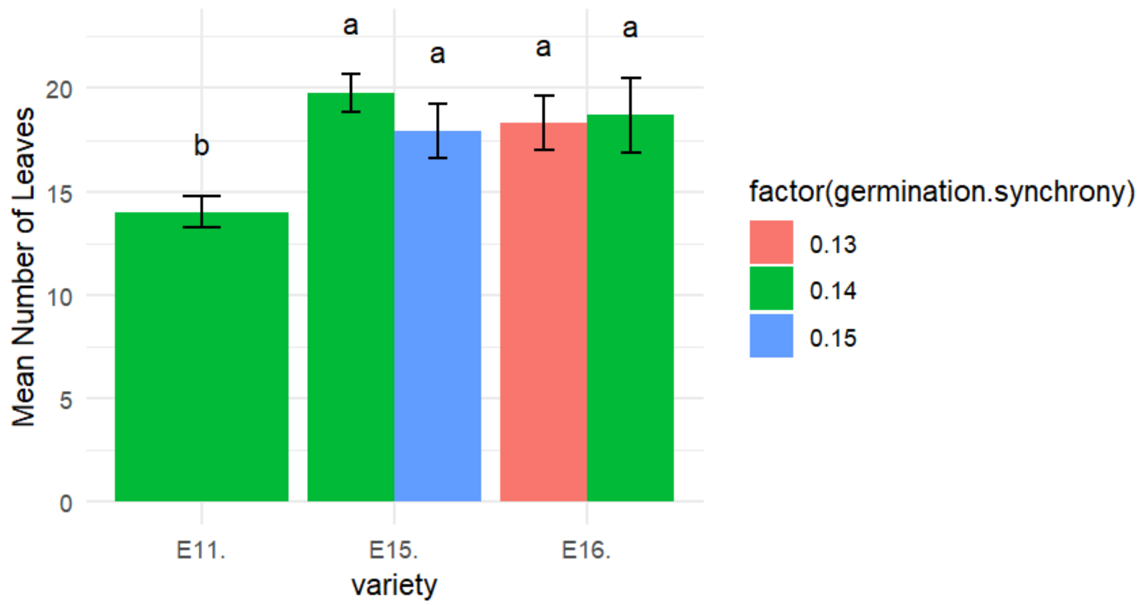

Figure 7: Number of leaves by Variety and Germination synchrony

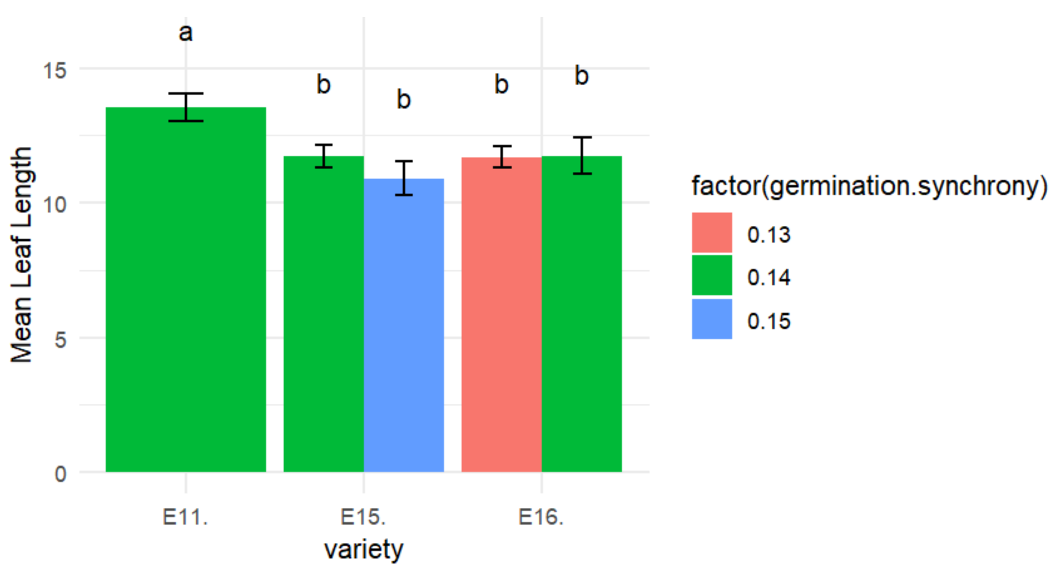

Figure 8: Leaf length by Variety and Germination synchrony

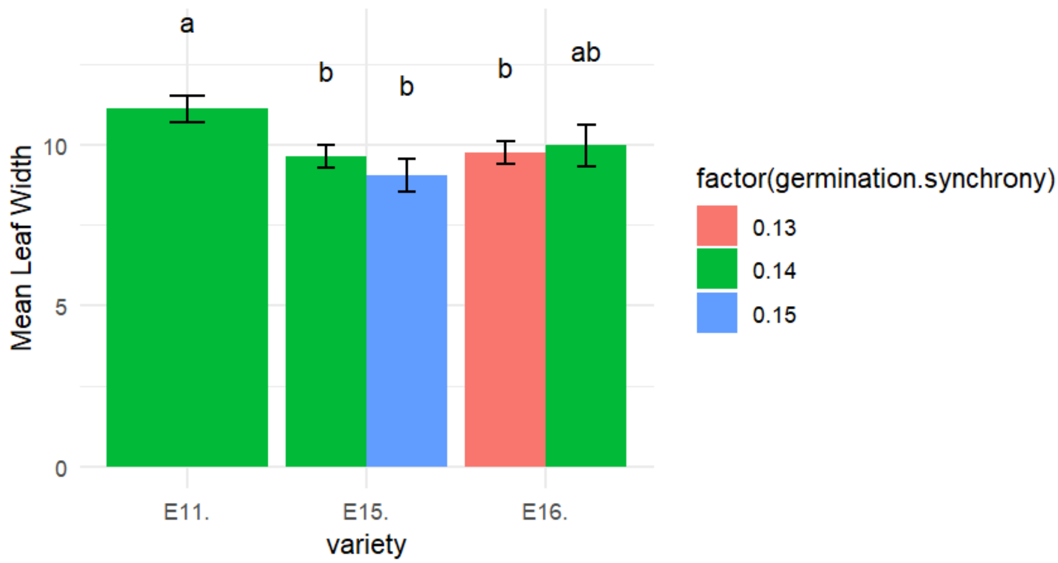

Figure 9: Leaf width by Variety and Germination synchrony

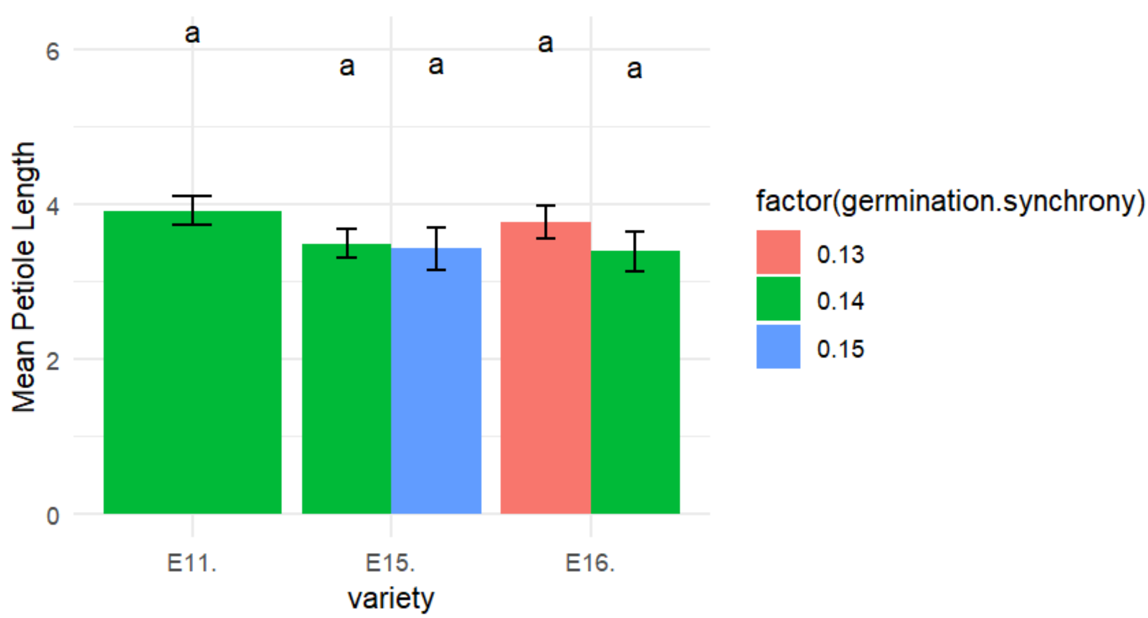

Figure 10: Petiole length by Variety and Germination synchrony

CHAPTER 5

This chapter presents the discussions for the interpreted data from chapter 4 in relation to other studies on seed quality, its effect on germination traits, and plant growth performance. The discussions compare and contrast the results firstly with the aim of identifying *Solanum aethiopicum* Shum varieties with stronger germination traits across seasons and secondly to identify desirable traits of growth performance in relation to early and uniform germination that is, germination synchrony

5.1 Discussion for objective 1

Evaluation germination rates for the three released varieties of *S.aethiopicum* Shum

The results from the interpretation reveal that both season and genotype had significant influence on germination characteristics that is germination percentage, mean germination time (GMT), germination velocity index (GVI), and germination synchrony. The season had high significant effect on all four germination characteristics indicating how they strongly impact germination performance. The variety affected germination performance implying that genetic differences among the genotypes contributed to variations in germination performance. However, there was significant impact on the interaction between season and genotype slightly for germination synchrony, strongly suggesting that the effect of season on germination traits varied depending on the variety. In germination percentage, the study significant variation was identified among the varieties, with E11 demonstrating higher germination performance in season 2, indicating its potential as favorable variety across multiple growing seasons. This result agrees with findings that highlight genetic variability as a factor in germination efficiency, where certain varieties outperform others in specific environmental conditions (Adebisi et al., 2013; Jahan et al., 2018). The interaction between season and genotype for germination percentage suggests that while both factors are critical for successful germination, they operate independently in influencing germination percentage relating with studies supporting independent contributions of variety and season to germination outcomes (Khodarahmpour, 2011; Lamichhane et al., 2021).

Results from mean germination time demonstrated significant variation influenced by both season and genotype, with the interaction effects suggesting that some genotypes particularly respond to changes over seasons. The shortest germination times recorded for variety E15 in season 1 and E15 in season 2 indicate a strong relationship between genetics and environmental adaptability, resonating with findings that agrees certain varieties exhibit greater plasticity in response to environmental factors (Sheng et al., 2021). This study's finding suggests that breeding programs might benefit from focusing on varieties with genotypes that adapt well to environmental variations other than high germination performance

Germination velocity index results support the interaction between genetic potential and environmental influence, as highest GVI values in varieties E11 for season 2 and E15 season 2 display their capability for rapid establishment under optimal growth conditions. Studies by Shezi & Adjetey, 2020 correlate GVI with overall plant vigor and successful crop establishment and so, the significant interaction between season and genotype observed in the study emphasizes the importance of selecting high GVI varieties while also emphasizing how these varieties respond to varying seasonal changes. Germination synchrony was significantly affected by both season ($p>0.001$) and variety ($p=0.0241$) although the minimal significance of the interaction ($p=0.0635$) indicates that while synchrony generally varies with seasons, response to environmental pressures might vary with varieties. This aligns with findings of Shu et al., 2017; Souza et al., 2013 which emphasizes the importance of synchrony for agriculture pointing out uniform germination that can lead to better crop management and yield frequency

5.2 Discussion for objective 2

Comparing effects of germination synchrony on crop growth in *S. aethiopicum* Shum

From the data analyzed, plant growth metrics are related to variety and germination synchrony influencing parameters and the study reveals that variety had a predominant effect on growth characteristics while germination synchrony had minimal influence. This finding matches with the general understanding that genetic variability as in the different Shum varieties offers a more significant impact on plant growth than timing and uniformity of germination.

At a significant effect of variety on plant height, ($p<0.005$), the result aligns with research that emphasizes the role of genetic factors in determining growth traits. Zhao et al argue out that leaf and plant morphology may be closely linked to genetic predispositions and so they often express variability depending on genetic background (Zhao et al., 2018). In this case, the superior height observed in variety E11 as compared to E15 and E16 illustrates how specific genetic traits can lead to enhanced growth performance. For plant canopy growth, E11 and E16 produced superior canopy size significantly different from E11 ($p=0.50$). This result supports the assertions made by Diouf et al., who confirmed significant variability among varieties concerning vegetative traits including plant canopy (Diouf et al., 2017)

With stem grith, germination synchrony had a significantly different relation at $p=0.004$. This observation suggests that synchronized germination positively affects stem robustness, essential for structural support for the plant and as well contrasts with the study which emphasized that plant morphological traits maybe moderated against environment variability (Rixen et al., 2022). This illustrates the interactions between environmental timing and genetic expression of traits. Leaf morphological traits that is number, length, and width showed a significance ($p<0.005$). The highest leaf count in E15, E16, and E11 respectively confirm that genetic factors greatly govern leaf attributes (Farooq et al. 2010) and the role of leaf dimensions in shaping plant success is widely supported to correlate leaf traits and overall growth efficiency (Falster et al., 2018; Chen et al., 2021)

Petiole traits that is length and color, presented lack of significance influence neither by variety nor germination synchrony at $p=0.176$ and $p=0.5778$. this result suggests inherent stability in these traits under varying conditions, aligning with interpretations from Macklin et al., 2022 regarding consistency of leaf trait (Macklin et al., 2022) Meanwhile, the significant difference observed in petiole color at $p<0.005$ proves that certain traits remain strongly influenced by genetic factors other than germination timing

CHAPTER 6

6.0 CONCLUSIONS

This study investigated the germination rate of the three released varieties of *Solanum aethiopicum* Shum under optimum conditions across seasons (stability) and was guided by the hypothesis that there was difference in levels of germination synchrony of the three released varieties of *S.aethiopicum* Shum across seasons. Thereby at $p > 0.005$, with p-value 0.0635, the study confirmed significant difference in germination synchrony among all varieties across seasons, resulting into failure to reject hypothesis 1 where the findings of the research show that E11 was the most stable variety across both seasons with high germination percentages, short germination times, and strong germination velocity. E15 produced a slight variability with slightly lower stability across both seasons and E16 demonstrated the highest variation across both seasons, suggesting lowest adaptability and stability

To determine subsequent plant growth at different germination synchrony levels across the selected varieties, the objective was hypothesized that there was difference in the effects of germination synchrony on subsequent growth across the selected varieties. Moreover, the study also confirmed significant differences in subsequent growth parameters at the various germination synchrony levels across the selected varieties thus failure to reject hypothesis 2. This is illustrated by the results which indicated that germination synchrony subsequently affects plant establishment but plant growth is more influenced by germination velocity index other than uniformity of germination

6.1 Recommendations

Further research by plant breeders to identify superior traits of stability levels in variety E11 as it exhibited better germination and growth performance over the seasons, to improve the genetic potential of other varieties. Additionally, optimization of cultivation of varieties E11 and E15 by farmers for stable yields over seasons

APPENDIX

Table 6: work plan and time frame

WORK PLAN/ TIME FRAME						BUDGET
Activity	Month 1	Month 2	Month 3	Month 4	Month 5	AMOUNT (UGX)
Concept development						
Proposal writing						
Proposal defense						
Experiment set up & maintenance						449,000
Data collection						
Data analysis						
Proposal, data sheet, & Dissertation printing						100,000
TOTAL						549,000

replication	day 1	day 2	day 3	day 4	day 5	day 6	day 7	day 8	day 9	day 10	day 11	day 12	day 13	day 14	total	Germination Percentage	Mean Germination Time	Germination Velocity Index	Germination Synchrony
3	0	0	0	4	8	11	18	10	10	7	4	1	0	1	74	74	7.54	10.58	0.13
1	0	0	0	0	8	13	15	21	19	12	1	1	0	0	90	90	7.83	12.02	0.16
1	0	0	0	3	7	17	25	8	13	3	2	0	1	1	80	80	7.30	11.63	0.18
1	0	0	0	2	7	16	22	12	9	4	2	1	1	0	76	76	7.33	10.95	0.17
2	0	0	0	1	7	11	17	20	15	13	1	1	1	0	87	87	7.87	11.63	0.16
2	0	0	0	2	6	18	24	9	14	2	3	1	1	1	81	81	7.46	11.51	0.18
2	0	0	0	3	5	15	21	14	10	5	3	2	1	0	79	79	7.54	11.13	0.16
3	0	0	0	0	7	14	15	20	17	11	1	1	0	0	86	86	7.79	11.54	0.16
3	0	0	0	4	8	16	26	7	12	4	2	0	2	1	82	82	7.32	12.00	0.17
3	0	0	0	1	8	17	23	13	8	4	1	1	2	0	78	78	7.33	11.21	0.18

Figure 11: Objective 1 data sheet

variety	week	replicate	germination synchro	plant number	plant height (cm)	plant canopy	stem girth(mm)	number of leaves	leaf length(cm)	leaf width(cm)	petiole length (cm)
E11.	1	1	0.14	plant 1	6.4	21	3	6	8.6	7.2	2.2
E11.	1	1	0.14	plant 2	6.8	25.8	4	6	7.5	6.9	2.5
E11.	1	1	0.14	plant 3	7.5	23.5	3	5	8.9	7.8	2.5
E11.	1	1	0.14	plant 4	6.2	19.9	2	5	7.3	6	1.9
E11.	1	1	0.14	plant 5	6.2	18	2	5	6.8	5.9	1.6
E11.	1	1	0.14	plant 6	7.4	21.3	3	6	7.5	8.1	2.4
E11.	1	1	0.14	plant 7	6	18.2	2	5	4.8	4	0.9
E11.	1	1	0.14	plant 8	7.5	22.5	2	6	7.5	6.3	1.9
E11.	1	1	0.14	plant 9	6.1	17.8	2	5	6.8	5.5	1.5
E11.	1	1	0.14	plant 10	6.3	18.1	2	6	7.5	6.7	0.3
E11.	1	2	0.14	plant 1	6.8	14	3	7	7.1	6.6	2
E11.	1	2	0.14	plant 2	5.8	22.7	2	5	7.7	6.2	1.5
E11.	1	2	0.14	plant 3	6.2	18.1	3	6	7.5	6.4	1.9
E11.	1	2	0.14	plant 4	6.3	19.1	5	11	10	7.3	2.6
E11.	1	2	0.14	plant 5	7.3	18.5	2	5	7.9	6.9	2.2
E11.	1	2	0.14	plant 6	6.2	16.2	2	6	7.6	6.2	1.9
E11.	1	2	0.14	plant 7	4.4	18.3	3	5	6.8	5.8	1.5
E11.	1	2	0.14	plant 8	6.1	24.2	3	6	8.2	7	2.7

Figure 12: Objective 2 data sheet

Figure 13: Mixing loam soil with poultry manure in the ratio of 2:1

Figure 14: steam sterilizing of mixed soil

Figure 15: watering plants in the screen house

Figure 16: data collection

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