CHARACTERIZATION OF POTATO GENOTYPES FOR DESIRABLE AGRONOMIC TRAITS, MORPHOLOGICAL ATTRIBUTES AND PROCESSING QUALITIES IN KIGEZI HIGHLANDS

BAGUMA GERALD

18/U/GMCS/19570/PD

A DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH AND GRADUATE TRAINING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN CROP SCIENCE OF KYAMBOGO UNIVERSITY

AUGUST, 2024

DECLARATION

I, GERALD BAGUMA, hereby declare that the work included in this dissertation is original research that I have conducted and has not been submitted to another University for the purpose of receiving a degree.

Signed.....

Date.....

APPROVAL

This dissertation has been submitted for examination with our approval as the University supervisors.

Signed..... Date.....

Dr. William Tinzaara

Kyambogo University

Signed..... Date.....

Dr. Tumuhaise Venansio

Kyambogo University

Signed..... Date.....

Dr. Namugga Prossy

National Agricultural Research Organization

(NARO-Kachwekano ZARDI)

DEDICATION

This research is devoted to my cherished spouse, Ms. Niwabimanya Maurensia, as well as our offspring, Geraldine Komuntare Muhumuza, Juliet Annie Kyokusiima, Taremwa Joseph Aguma, and Tashobya Joel Barinda.

ACKNOWLEDGEMENT

I sincerely thank the National Agricultural Research Organization (NARO) for helping to defray some of my post-graduate education expenses. In addition, I am indebted to my supervisors, Drs. William Tinzaara, Venansio Tumuhaise, and Prossy Namugga, for their guidance and assistance during my research project. In the same vein, I want to express my gratitude to Dr. Alex Barekye and Dr. Abel Arinaitwe, who have never failed to support and mentor me. Fellow graduate students, I appreciate your insights and words of encouragement. I want to express my gratitude to the academic staff at Kyambogo University's Faculty of Agriculture for providing me with the fundamental scientific knowledge and abilities. I also want to express my gratitude to the Kalengyere satellite research station and the Director of Research at KaZARDI for letting me utilize their field and laboratory facilities at no cost. More thanks go to Kachwekano ZARDI for donating the newly developed potato clones for my research. I would like to express my gratitude to Dr. Prossy Namugga, the head of the Kachwekano ZARDI's crop program, the employees of this research center, and the Kalengyere field station for their great assistance. You accomplished a wonderful job, my field helpers in both locations, may God continue to bless you. I want to express my sincere gratitude to my wife, children, mother, sisters, brothers, and friends for their prayers, advice, and encouragement given to me at a time when I most needed it. Last but not least, I give thanks to the All-Powerful God for helping me get this far. I will never stop praising and glorifying his name.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

LIST OF ACRONYMS

AMMI	Additive Main Effects and Multiplicative Interaction
ANOVA	Analysis of Variance
AUDPC	Area Under Disease Progress Curve
CIP	International Potato Centre
CRBD	Complete Randomized Block Design
DMC	Dry Matter Content
ECA	Eastern and Central Africa
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
GCA	General Combining Ability
GAP	Good Agronomic Practices
ICBN	International Code of Botanical Nomenclature
ICNCP	International Code of Nomenclature for Cultivated Plants
IPCA	Interaction Principal Component Analysis
KaZARDI	Kachwekano Zonal Agricultural Research and Development Institute
LSD	Least Significant Difference
MASL	Metres Above Sea Level

NARO	National Agricultural Research Organization
NEMA	National Environment Management Authority
PCA	Principle Component Analysis
PDI	Percent Disease Index
PLAA	Plant Leaf Area Affected
SCA	Specific Combining Ability
SWHAEZ	South Western Highlands Agro Ecological Zone
TSS	Total Soluble Sugars

ABSTRACT

Potato is an important staple food crop as well as a cash crop more especially for the highland areas of Uganda. There have been gaps in potato genotypes in regard to desirable growth traits, favorable morphological attributes and processing qualities in Kigezi highlands. The main objective of this research is to identify potato genotypes with favorable growth traits, morphological characteristics, and processing attributes that are adapted to the Kigezi Highlands of Uganda, in order to boost potato production. A total of 17 genotypes including 14 newly bred and three variety checks (Victoria, NAROPOT4 and Cruza) were used in the study. The experimental sites included Kalengyere at 2450 metres above sea level (m.a.s.l) and KaZARDI at 2,200 metres above sea level (m.a.s.l). Morphological data were recorded during the harvesting time after which samples were collected for processing and assessment of quality. The experiments were conducted during the wet months of March – June (Season A) and September – December (Season B) in 2020. The results revealed significant variations in growth and morphological traits among genotypes, seasons and within locations.Genotypes with desirable growth traits were 393220.54xNKRN59.48, NAROPOT4, and 393220.54. Genotype 57.8X59.41 was found to have poor agronomic traits. Genotypes NAROPOT4x77.54 and NAROPOT4x 39.107 were found with more resistance to late blight disease and genotype Victoria and 39266.18 were found more susceptible to late blight disease across the two sites. Genotypes which were found to be highly yielding were 59.41x220. 54 and NAROPT4x 38.107. The least yielding genotype across the two study sites and seasons was 39266.18. Genotypes with highest dry matter content were found to be 59.41x220.54 and 26.103x11.2 while those with low dry matter (<20%) were Kinigix19.17, and 395077.12.

Genotypes found with favourable qualities should be subjected to further evaluations in more diverse agro-ecological zones of Uganda.

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background

1.1.1 Origin and distribution of potato

Potato crop, (*Solanum tuberosum* L.) originated from Western South America. Contemporary landrace gene pools occur from 45° south in Chile to 12° Northern latitude in Colombia (Hawkes, 1990). Wild relatives of the potato has a much wider distribution range and occurs from northern Patagonia to the southern US and the Western Atacama desert to Eastern South America (de Haan & Rodriguez, 2016). The ongoing advancement of potato diversity in farmers' hands is forecasted to allow for transformation to climate emergency and continued food security in extreme agro-ecologies (Belay *et al.*, 2017). The case of the potato in its birthplace is special because landraces are still cultivated by cultivators in customary and market keeper systems. The Spanish conquerors introduced potatoes in Europe about mid-16th century (Bollier *et al.*, 2012). In the period between the 17th and the 19th century, Europeans supplied the crop to various regions beyond Europe (Suarez *et al.*, 2012). The potato in Uganda was launched around 1900 by Europeans as a backyard crop chiefly incorporated of European varieties (Iragaba, 2014). Since then especially in the highlands, the potato has gradually grown in prominence as a food and commercial crop. Few varieties with low altitude adaptations, below 1600 metres above sea level, have previously been developed, making the crop more significant in

Uganda's warmer lowlands. Formerly, the crop was best adapted to altitudes over 1700 metres above sea level (Adhikari *et al.*, 2015).

1.1.2 Importance of potato

Over 300 million metric tons of potatoes are produced worldwide each year. Potatoes, which are high in dietary fiber, simple sugars, vitamins, minerals, carbs, and protein, are consumed by over a billion people worldwide. As stated by Zaheer and Akhtar (2016). Due to rising urbanization and consumer demand for processed potato goods like French fries (chips) and crisps, the potato, one of the major staple crops in the Eastern and Central Africa (ECA) sub-region, is becoming more and more significant. The increased demand for fresh potatoes and their end products globally is causing a constant increase in the quantity of land utilized for potato production (Devaux *et al.*, 2020). The crop is a valuable food source, and its high calorie, protein, and vitamin C content significantly improve people's diets (Wijesinha-Bettoni & Mouillé, 2019).

In developing nations, particularly in the densely populated tropical highlands, it also serves as a starting point for revenue and employment (Herrero *et al.*, 2013). Potatoes are a viable component of urban gardening because of their high nutritional content and simplicity of cultivation. This might improve food security for approximately 800 million people worldwide (Orsini *et al.*, 2013). The potato's adaptability to a wide range of agro-ecologies, its suitability for various agro-inputs, and its high productivity make it a thriving crop (Omomowo & Babalola, 2021). Thus, potato has a great deal of promise for meeting the food demands of low-income individuals in both urban and rural locations. Potatoes grow well in

areas with plenty of labor and little land, which are common in many tropical highlands in developing nations (FAO, 2008). Additionally, it has a large unrealized potential for higher productivity and output, especially in some marginal farming areas where the yield potential of other crops is quite low (FAO, 2008). Because potatoes are easily adapted to the prevalent low rainfall and high temperature regimes, they give farmers more opportunities than most other root and tuber crops, especially in light of global climate change and decreased rainfall reliability (Majaliwa *et al.*, 2010).

1.1.3 Major potato production constraints

Potato production is influenced by both biotic and abiotic factors. Insect pests, bacterial, fungal, and viral diseases are examples of biotic forces. The main disease harming potato output, especially in Uganda's highlands, is late blight. The most dangerous potato disease, late blight, is brought on by Phytophthora infestans and causes a 40% to 60% reduction in production. The cost of fungicide spray is estimated to be $100-300/ha which represents 25% of the production cost compared to when having resistances of late blight which makes a cost saving of $2.5 to 7.5M considering 102,000 ha of potato (2014). This means that when using potato genotypes which are susceptible to late blight disease, 25% cost is wasted on buying and spraying chemicals to control the disease. The abiotic factors hindering potato production in Uganda include inadequate moisture supply, low soil fertility and drought owing to high temperatures (Ferris *et al.*, 2001). Several of these issues are made worse by farmers' inability to use higher-yielding inputs in underdeveloped countries (FAO, 2008). Because of their low incomes,

farmers in developing nations are less likely to employ higher-quality inputs, which can exacerbate some of these concerns (FAO, 2008). As a result, the quantity of potatoes produced in developing nations like Uganda's highlands is insufficient to meet the expanding demand for potato-producing businesses due to the lack of land in the places where potatoes are mostly farmed.

1.2 Statement of the problem

In Uganda, potato is mainly grown in highland areas (Altitude: 1000 to 3000 metres above sea level); and four regions are well known for potato production including Kigezi region, Rwenzori region, Elgon region, and West Nile region. Surprisingly, the Kigezi region is the top potato producer with Kabale and Kisoro districts alone producing over 60% of the 165,000 tons of the national output in Uganda. However, Uganda's potato yields have remained low at only 4.8-7 t ha^{-1} (FAOSTAT, 2016), much below the 25 t ha^{-1} potential that is achievable with excellent management and the use of the right cultivars. These low yields are correlated with both the genetic make-up and the high severity of diseases. The existing high-yielding potato varieties have reduced in productivity and have become vulnerable to diseases, particularly the late blight disease (*Phytophthora infestans)*. Most of the available potato varieties are not suitable for the processing industry which has become a great concern and demand for the processing industry. Considering all these scenarios, there is an urge to develop new varieties that are high yielding, resistant to late blight and with good processing qualities. To achieve this uphill task, several traits in potato genotypes have been characterized in different environments (altitudes from 2200 to 3450 m.a.s.l)

of Kigezi highlands where most of Uganda's commercially farmed potato varieties are best grown. The availability of potato varieties with the precise infusions of specific tuber processing qualities to fit into the processing and marketing chain is limited within the Ugandan market, despite the growing significance of processing in the country's potato economy.

This study is aiming at determining potato genotypes with desirable growth traits including late blight resistance, desirable morphological attributes and with desirable processing qualities. It also aims at determining high yields in relation to adaptation and stability in different environments.

1.3 Objectives of the study

1.3.1 General objective

This study's overall goal is to contribute to the improvement of potato production through the characterization of high yielding potato genotype with desirable growth traits, morphological and processing qualities adaptable to south-western highlands agro-ecological zone (SWHAEZ).

1.3.2 Specific objectives

The specific objectives of the study are;

i. To determine the growth traits of the newly bred potato genotypes and their tolerance to late blight disease at different altitudes in the Kigezi highlands.

ii. To determine the tuber morphological attributes and yield of the newly bred potato genotypes at different altitudes in the Kigezi highlands.

iii. To determine the processing qualities of the newly bred potato genotypes grown at different altitudes in the Kigezi highlands.

1.4 Hypothesis of the study

i. Potato genotypes exhibit favorable agronomic traits, including desirable maturity and tolerance to late blight disease.

ii. Potato genotypes display diverse responses to different altitudes in terms of morphology, yield, and stability.

iii. Potato genotypes possess desirable processing qualities.

1.5 Scope of the Research

Potato genotypes with desirable agronomic and morphological traits, such as early maturation, tuber yield, and late blight resistance, were characterized and analyzed as part of this research project in the Kigezi highlands. Determining the impact of environment and genotype on late blight resistance and total tuber yield was the aim of the study. Under this experiment, different potato genotypes with numerous late blight resistances were studied for two separate locations due to their varying altitudes, soil types, rainfall patterns and temperature regimes. The study was conducted in two distinct seasons: Season A (March – June 2020) and season B (September – December 2020).

1.6 Significance of the study

For farmers and processors operating on a small or large scale, the study's conclusions are crucial. Some genotypes of the seventeen potato genotypes that were described over the course of two seasons (Season A and Season B 2020) at two locations—Kalegyere and KAZARDI—were found to have

favorable growth properties, including plant vigor, plant height, stem number, flowering days, and early maturity. Genotypes with desired morphological traits on tuber shapes, eye depth, skin colour, and fresh colour were found. Favourable processing qualities were also found in some of the genotypes characterized and were found adaptable in Kigezi highlands for potato production. Potato genotypes with early maturity, late blight tolerance, and high yields were identified. This is very important as the genotypes found with such traits help to curb hunger and reduce production costs since farmers nowdays do farming as a business. Some genotypes were found to have traits that meet the processing qualities and with high acceptability degree for uptake by the market. Therefore if these varieties are released and utilized by farmers under good management systems, they will contribute significantly to household income and nutritional food security. Potato genotypes with good morphological and processing qualities were determined to bridge the gap in the processing industry. The genotypes which were found with suitable processing qualities are very important for the processors especially on chips, crisps and other value additions that are on high demand. Potato breeding genotypes with wide adaptation and the ability to thrive at different altitudes were identified and recommended for future release. This is very important for potato breeders and extensionists as the genotypes found adaptable and stable in different altitudes are source of genes for future research and variety deve

CHAPTER TWO

LITERATURE REVIEW

2.1 Classification of potato

According to Reddy *et al.* (2018), the potato is a perennial plant in the genus Solanum of the family Solanaceae. Along with other important crops, the family also includes frequently grown items including tobacco, eggplant, tomato, pepper, and tree tomatoes. Under optimal development conditions, the cultivated potato, an autotetraploid with 48 chromosomes, is an annual herbaceous dicotyledon crop that normally develops to a height of 30 to 100 cm (Reddy *et al.*, 2018).

2.2 Growth stages of potato

In the development of potato plants, five distinct growth stages are frequently identified (Yang *et al.*, 2015). Sprouts emerge from the eyes at the beginning of the first stage of sprout development, and they emerge through the ground at the end. Photosynthesis begins during this stage. These first two stages require between 30 and 70 days. The length of time varies according on the cultivar, physiological age of the tubers and environmental conditions. The tuber initiation/tuber set is the next phase. Tubers form at the tips of the stolons but do not yet enlarge, which is characteristic of this. Photosynthesis begins at this point. Depending on the surroundings, these first and second stages can take anywhere from 30 to 70 days. The environment, the tubers' physiological age and the cultivar type all affect how long it takes.

2.2.1 Potato production in Uganda

Most of the crop is grown in the highlands of south-western Uganda, with Kabale and Kisoro producing over 60% of the country's total potato production (Figure 1). Potato is predominantly farmed in Uganda as a food security crop. Additional potato-producing regions include Mbarara (6.2%), Mubende (2.3%), Kapchorwa (2.2%), Mbable (1.0%), Nebbi (0.6%), Bushenyi (0.5%), Sironko (0.4%) and Masaka (0.1%) (Namugga, 2017). In Uganda, between 200,000 and 300,000 households grow potatoes for food, as a cash crop, or for both (Ferris *et al.*, 2003). In terms of Africa's production of potatoes, Uganda comes in ninth, (Kesiime *et al.*, 2014). However by both African and global standards, Uganda's average yield, estimated at 7.0 t ha^{-1}, is among the lowest.

In order to fulfill rising demand, potato cultivation has recently been progressively expanding to non-traditional production zones, especially at low altitudes. This is because there is a greater need for fresh potatoes, especially in cities. Potato (*S. tuberosum* L.) is an important crop for food supply and income generation in Uganda. Potato varieties like Cruza, Kimuri, Kinigi, Mbumbamagara, Rutuku, Rwashaki and Victoria are often grown in Uganda. Furthermore, Kachpot1, Naropot1, Naropot2, Naropot3, Naropot4, Naropot5 and Naropot6 are some further new potato (*S. tuberosum* L.) genoypes that NARO recently introduced and have good processing properties (Kajunju *et al.*, 2022).

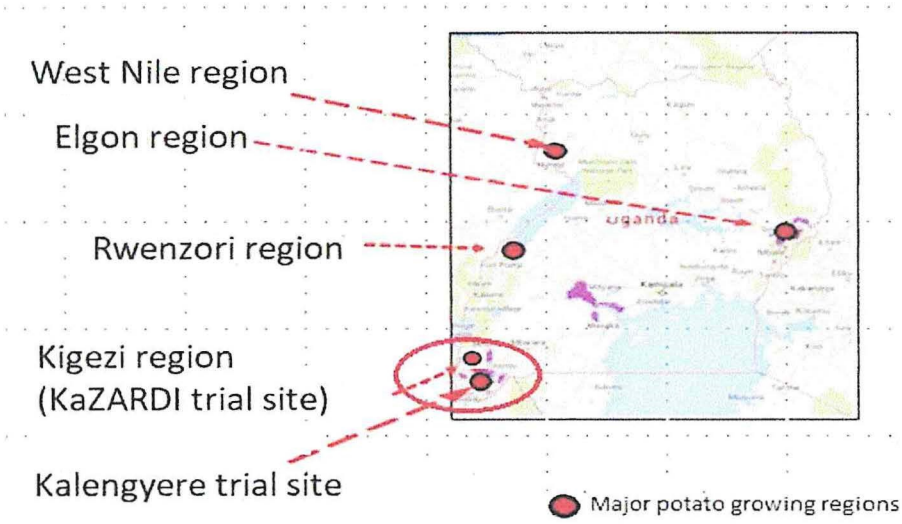

Figure 1: Major potato-producing regions in Uganda

2.2.2 Potato maturity period

Maturity of potato (*S.tuberosum* L.) depends on the type of a genotype as diferent genotypes or varieties have different maturity periods. Most potato genotypes have maturity periods between 70 to 120 days with few genotypes reaching up to 150 days (Heltoft *et al.*, 2017). To know that the potato crop has matured, we consider monitoring of acrop from the time of planting up to harvesting. Potato growth stages are frequently delineated by the following terms: tuber sprouting, vegetative development, tuber initiation, tuber bulking and plant senescence (Oliveira *et al.*, 2014). Culture techniques can be adjusted to help the crop reach its maximum genetic maturity potential, including the use of clean seed, physiological seed maturity, early planting, nutrients, and pest and disease management. To gauge the maturity of potatoes, the vine features are frequently seen ripe (Schumacher *et al.*, 2021). The crop attains maturity when the leaves of the potato plant begin to change (Lizana *et al.*, 2016). The maturity class of potatoes is often determined by potato breeders using physiological changes

in the potato vine. Changes in the entire plant, including a reduction in leaf growth, blooming, and fruit set, are linked to the formation of tubers (Malhotra *et al.*, 2017).

The resources in a given environment that support optimal plant growth and yield can be used to explain the yield of a crop in that environment (MacLaren *et al.*, 2020). A crop's response to several environmental factors, including light, temperature, soil moisture content, air pollution and soil stressors including salt, acidity and mineral deficiency varies depending on the situation (Xu, 2016).

Genetic and environmental factors as well as their interactions, determine the number of seeds produced by each genotype and the percentage of seeds that mature. In certain stressful situations, the plant might produce less viable seeds (Stoeckem *et al.*, 2020). Environmental factors encountered during the growth season affect potato output through decreasing photosynthetic function and efficiency, preventing stolon and tuber start, and altering photosynthetic partitioning (Oraby *et al.*, 2015).

Generally speaking, the amount of days that pass between planting and the onset of senescenceor leaf ripening, determines the maturity classes into which potatoes fall. Bulking rate is directly affected by this (Obidiegwu *et al.*, 2015). Because they can withstand changes in the weather, the sustainability of potato production will be guaranteed.

2.3 Breeding for earliness in potato

Breeding potatoes for early maturity has been seen advantageous since it allows for escape from late-season diseases like late blight (Wang-Pruski *et*

al., 2018). However, in order to create flexible cultivars that can adapt to diverse environments, Uganda has not intentionally pursued potato breeding for earliness.

2.4 Combining abilities in potato breeding.

The concept of combining ability suggests that during hybridization processes, the parents can combine with one another in order to pass on advantageous genes or traits to their progenies (Owusu *et al.*, 2017).

While specialized combining ability (SCA) is caused by non-additive gene effects, general combining ability (GCA) is typically linked to additive gene action (Sulutana *et al.*, 2015).

In the F1 generation, GCA and SCA are both fixed and are crucial for conditioning traits in potato breeding. According to Muthoni *et al.* (2015), in crosses between unrelated parents, GCA appears to be much larger than SCA for tuber production and quality parameters, while SCA appears to be more significant in crossings between related parents. GCA effects were shown to be more significant than SCA effects in terms of crop maturity (Hirut *et al.*, 2017).

2.5 Genotype by environment interaction

The term "genotype by environment" (G x E) interaction describes how different genotypes react to various environments (Begna, 2020). Multi-location trials (MLTs) are typically carried out to verify genotype performance for significant variables and assess the overall adaption or stability of genotypes that show promise in on-station experiments.

Additive Main Effects and Multiplicative Interaction (AMMI) analyses conducted on multi-location trials (Anchico *et al.*, 2023) offer insights into the combined performance of genotypes, environments, and genotype by environment (G x E) interactions across many sites. Breeding progress and the assessment and choice of better genotypes are influenced by the strength of G x E interactions. Factors responsible for genotype adaptation can be identified with the aid of interactions.

2.6 Factors affecting potato production

Abiotic and biotic variables influence the yield of potatoes. Temperature and precipitation-related events are the main abiotic restrictions on potato production (George *et al.*, 2017). Heat waves throughout the growing season and during the bulking of tubers can cause the quality of the tubers to decline and crop growth to be temporarily slowed down or stopped (Gericke, 2018). Resuming tuber growth when temperatures drop again causes malformation and secondary growth signs, like knobbiness and growth fissures (Van der Waals, *et al.*, 2016). Potatoes are susceptible to several precipitation-related occurrences, such as excessive rain during tuber growth that causes water logging, crops that perish in the soil from asphyxiation, or excessive rain during harvest that makes harvesting impossible (Denner *et al.*, 2012).

Biotically, there are also factors that affect the production of potato. The frequency and severity of diseases brought on by bacteria, fungi, and viruses that infect potatoes, as well as pests like nematodes, tuber moths, aphids, and leaf miners. Bacteria, fungi, and phloem-limited pathogens, including as viruses and virus-like agents, are the main causes of potato infections

globally. Several viruses have been identified to infect potatoes in the East African region. Among these are the potato leaf roll virus (PLRV), potato virus Y (PVY), and potato virus A (PVA), the presence of which has been verified in Kenya's main potato-growing zones (Gildemacher *et al.*, 2009). According to Juneidi *et al.* (2012), there is a distribution of potato viruses S (PVS), PVX, Potato virus M (PVM), PLRV, and PVY in Ethiopia. Another obstacle to the production of potatoes is late blight. *Phytophthora infestans* is recognized as the causative agent of late blight disease (Razukas *et al.*, 2009). The disease can be severe when the weather is favorable for an extended period of time, with high relative humidity, cool temperatures, and moisture content in the soil (Muhinyuza *et al.*, 2007). One of the most destructive diseases to many plants is late blight. Globally, late blight causes losses amounting to billions of euros per year, primarily in the potato industry. The fungus initially infects leaves and stems before spreading to all plants (Razukas *et al.*, 2008). According to Njoroge *et al.* (2019), there is a European lineage of the pathogen known as "2_A1" that predominates in Rwanda, and there is also a minor amount of the old "US-1" lineage that is still there. Thus, it was established that 2_A1 is replacing the ancient US-1 lineage in the East African region. Ralstonia solanacearum is the causative agent of potato bacterial wilt (PBW), also referred to as potato brown rot. It is one of Uganda's most common potato disease (Mutimawurugo *et al.*, 2019). The production of potatoes is threatened by potato bacterial wilt, which is evident in the soil for a considerable amount of time (Mutimawurugo *et al.*, 2019). The tubers' round shape, medium eye depth, and comparatively big size

support their acceptability among the kinds. These morphological characteristics are influenced more by cultural norms and genotype. While eye depth affects peeling time and cost, potato shape and size mostly affect peeling and slicing losses or recovery (Singh and Kaur, 2016). According to research by Pino and Vergara (2021), tuber flesh color of grown potatoes worldwide typically ranges from white to dark yellow. Given that flesh and skin colors are also genetically determined, this variation can be linked to the genotype (Calliope *et al.*, 2018). When choosing potato tubers, one of the main quality factors taken into account by processors and customers is flesh color (Singh and Kaur, 2016). According to Kajunju *et al.* (2021), potatoes with cream or yellow flesh color work well for processing into French fries and crisps because they yield a light golden product that consumers like (Soison *et al.*, 2015). On the other hand, potatoes with white flesh color work best for processing into potato starch and flour.

Even though potatoes are significant in Uganda, their full potential has not yet been reached. Some of the main obstacles influencing the potato value chain include the use of non-improved or uncertified varieties and minimal industrial processing or value addition of the product (Mbowa and Mwesigye, 2016). Value addition that would be essential to modernizing the entire potato value chain is still scarce in Uganda. Value addition not only offers a way to store excess from one season to the next, but it also helps extend shelf life, make handling easier, and lower transportation expenses (Abong *et al.*, 2010).

It has also been observed that value addition generates jobs by bridging the gap between industry and agriculture. Furthermore, in response to evolving

lifestyles and the growing public desire for healthy diets, it manufactures "convenience" foods and offers goods with higher nutritional value. A crucial and essential stage in the food processing is the selection of raw materials based on their physical and chemical properties (Keijbets, 2008). As a result, in order to satisfy consumer demand for high-quality products, processors need potato varieties with certain qualities, which is why modern potato breeding is driven by this need (Singh and Kaur, 2016). Due to this, there is now a desire for unusual potato cultivars that might not be found in some small-scale potato seed systems.

CHAPTER THREE

EVALUATING GROWTH TRAITS OF NEWLY BRED POTATO GENOTYPES AND THEIR RESISTANCE TO LATE BLIGHT DISEASE AT DIFFERENT ALTITUDES

3.1 Introduction

Potatoes are a significant commercial and food security crop in the highlands of East and Central Africa at agro-ecological altitudes greater than 1800 meters above sea level. A significant amount of Uganda's food supply and income come from this crop, which is mostly grown in the Kabale and Kisoro districts (Kesiime *et al.*, 2014). In the world, potatoes come in third place among food crops. This crop is grown by more than 480,000 smallholder farmers in Uganda. Uganda is the eighth-largest producer of potatoes in Sub-Saharan Africa, yielding an average of 400,000 tons annually from an average of 100,000 acres. Potato production is concentrated in the southwest highlands of Kabale, Kisoro, and Kanungu, which produce around 87% of the crop. To ascertain the appropriate growth characteristics and late blight disease resistance in potatoes, a study was conducted using 17 genotypes with varying yield, maturity duration, late blight resistance, and other qualities favored by farmers. The main objective was to determine the resistance, morphological, and agronomical variability of different potato genotypes for the breeding program in the Kigezi highlands.

3.2 Materials and methods

Potato genotypes were chosen from recently developed potato germplasm that is being kept as tiny tubers at KaZARDI. Seventeen potato genotypes in total were employed in the study, of which three commercial varieties (Cruza, Victoria, and NAROPOT4) were compared with fourteen newly developed genotypes. In two locations with varying altitudes, during two growing wet seasons in 2020—March–June (Season A) and September–December (Season B) and G x E interactions were examined for 17 genotypes.

The experiment was planted using a fully randomized block design (CRBD) with three replications following bush clearance and land openings (primary and secondary cultivation). Two rows, each containing five tubers, were planted in each plot 30 x 75 cm seed tuber spacing and a 1-meter interplot distance were used for planting. The fertilizer compound NPK 17:17:17 was applied twice to each of its portions at a rate of 100 kg/ha in order to promote vigor and tuberization. Before inserting the seed tubers, the first batch of fertilizer was applied during planting and completely mixed with the soil. To promote vegetative development and flower output, the second half of the fertilizer was administered as a top dressing forty days following planting. Fertilization, weed control, plant protection, and irrigation are examples of agronomic procedures that were used. The processes of weeding and earthing up were completed at 40 and 55 days, respectively. After planting, the crop stalk was clipped (dehaumed) 110 days later, and it was harvested 14 days later. Morphological characteristics, including eye depth,

skin colour, flesh colour, and tuber form, were noted following harvesting at every location and during every season.

3.2.1 Experimental sites and field preparation

The experiments were carried out at the Kachwekano Zonal Agricultural Research and Development Institute and the Kalengyere Research Station. The coordinates of the Kalengyere research station are 0290 47.79'E 010 13.26'S, or 2,450 m.a.s.l, while KaZARDI is 0290 57'E 010 16'S, or 2,200 m.a.s.l. The two sites are located in Uganda's southwest. The year 2020 saw the wet months of March through June and September through December when studies were carried out to assess the stability and performance of 17 genotypes. Though at different times and in varying amounts and intensities, the two locations receive bi-modal rainfall. The two rainy seasons at the two sites are separated by a brief dry spell that lasts anywhere from thirty to sixty days, depending on the location. The above reasons justify why two study sites were put into consideration in addition to G x E interactions.

3.2.2 Selection and establishment of potato genotypes

Potato genotypes were chosen from newly bred and maintained potato germplasm at KaZARDI. The study involved a total of 17 potato genotypes (Table 1), in which 14 newly bred potato genotypes were compared with three commercial varieties (Victoria, NAROPOT4, and Cruza).

Table 1: Potato genotypes used in the study

S/No	Genotype	Skin color
1	57.8x59.41	Red
2	391919.3	Creamish purple

3	NAROPOT4	Red
4	395077.12	Cream
5	59.41x220.54	Red
6	393220.54	Creamish red
7	Victoria	Red
8	393220.54xNKRN59.48	Red
9	NAROPOT4x38.107	Red
10	26.103x11.2	Red
11	393077.54	Creamish red
12	Kinigix19.17	Purple
13	Kimurix59.58	Cream
14	Cruza	Creamish purple
15	39266.18	Red
16	39220.54x395011.2	Creamish red
17	NAROPOT4x77.54	Red

Source: Kachwekano ZARDI, 2020.

3.2.3 Data Collection

3.2.3.1 Determination of growth traits of potato genotypes

Data were collected from germination to the senescence stage when genotypes were ready for harvesting (Plate 1). The number of plants that germinated, plant height, number of stems, number of flowers, blooming date, number of surviving plants per plot, number of plants infected with late blight, and number of leaves per plant impacted by late blight disease were among the growth parameters evaluated.

Plate 1: Collection of data on growth traits

3.2.3.2 Flowering days and maturity periods for the 17 genotypes

Agronomic data collection started 40 days after planting up to when the crop attained its physiological maturity. Flowering data was done per plot of the experiment in each of the 3 replications for each genotypes. Data on days to flowering and maturity periods for the 17 genotypes were recorded every after seven days when genotypes reached 50% flowering. This data was gathered up until the plants senescenced or the beginning of leaf yellowing (physiological maturity). The senescence period was reached after the genotypes attained their maximum maturity periods and started weathering.

3.2.3.3 Late blight resistance determination among potato genotypes

Data on each of the ten plants in each plot and replication were gathered throughout the first growing season. Since the size of the plots and the quantity of tubers rose from 10 to 30 in the second season, only 4 plants were randomly sampled for the second season. This is because, going into

season two, the seed tubers had grown from the previous season, acting as a multiplier. Every genotype of the 17 potato genotypes included in this investigation has data on the emergence of plant diseases. The late blight disease's incidence and severity were calculated appropriately. By comparing the infected green and non-green leaf sections using a 1–9 scale developed by the International Potato Center (CIP), the degree of late blight lesions on leaves and stems was visually assessed. From 1 (no symptoms) to 9 (all leaf area with symptoms), scores varied. For each plot, the average percentage of blighted foliar area was determined. Plant leaf area affected, or PLAA, is a standardized method for measuring disease severity that was used for weekly assessments to monitor the development of late blight on leaves (Forbes *et al.*, 2014). Plants were harvested at the conclusion of the season, and the number of tubers on each plant was tallied. When the plants were harvested at the end of the growth season, the number of tubers on each plant was counted, weighed and divided into three categories: small, medium, and large. Data on traits associated with yield and reaction to late blight infection were acquired.

3.2.4 Statistical data analysis

Using the method of Campbell et al. (1990), the extent of the disease was calcuiated as the area under the disease progress curve (AUDPC).

AUDPC = $\sum_{i=1}^{n}[(X_i + X_{(i-1)})/2][t_i - t_{(i-1)}]$

where $t_i - t_{(i-1)}$ is the time difference between two successive disease severities, X_i is the current disease severity, and $X_{(i-1)}$ is the previous diseases everity.

Analysis of variance (ANOVA) and means separated by least significant difference (LSD) were used in Genstat 11th edition to analyze data on flowering days and maturity periods with a 95% confidence level.

3.3 Results

3.3.1 Growth traits of potato

Growth traits varied among the genotypes, seasons and study sites of Kalengyere and KaZARDI. Among the 17 potato genotypes that were characterized, genotypes at Kalengyere generally registered better agronomic attributes than KaZARDI location in terms of plant vigor, plant height, and number of stems for each plant. During the first season, genotypes 393077.54, 393220.54, 59.41x220.54, Kinigix19.17, NAROPOT4 NAROPOT4x38.107 and NAROPOT4x77.54 were found to have very good plant vigor. Only genotype 57.8x59.41 was found with poor vigor. Potato genotypes with highest plant height were NAROPOT4X38.107, 393220.54, 393077.54, NAROPOT4x77.54, 393220.54xNKRN59.48, KinigiX19.17, Cruza, 59.41x220.54, NAROPOT4 and 26.103x11.2. The genotypes with short plant height was found to be 57.8x59.41. The number of stems per genotype varied from 1 to 2 hence indicating less significant difference ($P>0.5$). Genotype 57.8X59.41 had the number of stems as three and 13 genotypes two stem numbers (Table 2). Genotypes with the highest means in plant vigor were; NAROPOT4x38.107, NAROPOT4x77.54, Cruza, 59.41x220.54, 395077.12, 393077.54 and 39220.54x395011.2. Genotype with the least means in terms of height was 57.8x59.41. In general, the genotypes that were characterized did not differ significantly in terms of

stem counts. It was discovered that the majority of potato genotypes differed significantly ($P<0.05$) in terms of plant vigor. The most outstanding genotypes in plant vigor were; NAROPOT4x77.54, 59.41x220.54 and 393077.54. These were followed by NAROPOT4x38.107, NAROPOT4 (Variety check), Kinigi x 19.17, Cruza(Variety check), 393220.54 x NKRN59.48, 393220.54, and 26.103 x 11.2 (Table 2).

Table 2: Means of different growth traits of potato genotypes at Kalengyere (A) and Kachwekano Zonal Agricultural Research and Development Institute (B) sites

A: Kelengyere

Genotype	Season one			Season two		
	Plant vigor	Average plant height (cm)	Number of stems	Plant vigor	Average plant height (cm)	Number of stems
26.103X11.2	6.2±0.99^{cd}	48.87±29.31^{d}	2.37±0.85^{ab}	7.07±1.34^{d}	47.79±29.12^{c}	2.37±0.85^{c}
391919.3	6.93±1.92^{d}	51.20±30.96^{e}	2.4±0.81^{ab}	6.4±1.19^{c}	47.34±28.79^{c}	2.4±0.81^{c}
39220.54X395011.2	7.2±1.69^{d}	52.60±31.57^{e}	2.4±0.81^{ab}	6.60±0.81^{cd}	49.24±30.63^{c}	2.40±0.81^{c}
39266.18	4.53±1.01^{c}	39.16±20.80^{c}	1.93±0.69^{a}	4.27±1.23^{b}	37.23±23.16^{b}	2.17±0.79^{b}
393077.54	7.0±1.82d	51.57±31.79^{e}	2.2±0.76^{a}	8.00±1.64f	54.52±32.46^{de}	2.17±0.79^{b}
393220.54	6.4±1.50^{cd}	52.56±32.16^{e}	1.97±0.67^{a}	7.87±1.94^{ef}	55.94±32.69^{e}	1.97±0.67^{a}
393220.54XNKRN59.48	5.2±1.10^{c}	48.14±27.68^{d}	2.63±1.22^{c}	7.47±2.50^{e}	53.12±32.19^{d}	2.40±1.04^{c}
395077.12	7.6±1.83^{e}	53.77±32.23^{e}	2.13±0.82^{a}	6.60±0.81^{d}	47.06±29.46^{c}	1.93±0.69^{a}
57.8X59.41	2.4±0.93^{a}	29.49±16.16^{a}	3.23±1.072^{c}	3.80±1.63^{a}	31.21±20.09^{a}	2.87±1.17^{cd}

59.41x220.54	7.13±1.77^{d}	52.567±32.5^{e}	1.755±0.44^{a}	8.00±1.64^{f}	56.95±33.11^{e}	2.20±1.03^{b}
CRUZA	7.6±1.83^{e}	53.67±31.19^{e}	2.4±0.81^{ab}	7.60±1.83^{e}	51.98±31.12^{c}	2.40±0.81^{c}
KIMURIX59.58	5.67±1.77^{bc}	41.98±24.99^{c}	2.6±1.07^{c}	6.13±1.46^{c}	45.64±28.68^{b}	1.63±1.03^{a}
KINIGIX19.17	6.53±1.94^{d}	50.19±29.18^{e}	2.4±0.81^{ab}	7.13±2.73^{d}	50.92±31.23^{c}	2.17±0.79^{b}
NAROPOT4	6.6±1.52^{d}	50.65±29.45^{be}	2.4±0.81^{ab}	7.73±2.20^{ef}	55.15±33.55^{e}	2.75±1.12^{cd}
NAROPOT4X38.107	7.6±1.83^{e}	54.72±29.845^{f}	2.4±0.81^{ab}	7.53±1.57^{e}	51.83±30.73^{c}	2.40±0.81^{c}
NAROPOT4X77.54	7.47±2.08^{e}	54.68±31.09^{f}	2.63±1.03^{c}	8.00±1.64^{f}	57.61±34.29^{e}	2.40±0.81^{c}
VICTORIA	4.4±0.93^{b}	37.16±19.31^{b}	2.4±0.81^{ab}	4.60±0.81^{b}	41.75±23.84^{b}	2.40±0.81^{c}

Different letters imply significant differences at 5%. The difference are compared across columns for all genotypes for season one and season two at Kalengyere site. Variety checks (Cruza, NAROPOT4 and Victoria).

B: Kachwekano Zonal Agricultural Research and Development Institute

Genotypes	First season			Second season		
	Plant vigor	Average plant height (cm)	Number of stems	Plant vigor	Average plant height (cm)	Number of stems
26.103X11.2	6.40±0.93^{cb}	50.22±25.55^{c}	2.03±0.67^{a}	6.53±1.46^{cd}	48.46±25.12^{c}	2.03±0.67^{a}
391919.3	6.40±0.93^{cb}	49.30±24.75^{c}	2.27±0.78^{a}	6.53±1.46^{cd}	50.52±26.64^{c}	2.27±0.78^{a}

39220.54X395011.2	6.40±0.93^{cb}	47.70±24.62^{c}	1.80±0.41^{a}	6.53±1.46^{cd}	49.48±24.88^{c}	1.80±0.41^{a}
39266.18	4.40±0.93^{b}	40.93±21.15^{a}	2.23±0.82^{a}	4.27±1.78^{b}	43.58±22.45^{b}	2.23±0.82^{a}
393077.54	8.00±1.64^{d}	54.22±27.17^{d}	1.80±0.41^{a}	6.87±1.74^{d}	56.41±28.43^{d}	1.80±0.41^{a}
393220.54	8.00±1.64^{d}	54.02±26.81^{d}	1.80±0.41^{a}	7.20±1.92^{d}	55.99±28.23^{d}	1.80±0.41^{a}
393220.54XNKRN59.48	7.93±1.72^{d}	52.96±27.14^{c}	2.27±0.78^{a}	6.20±1.00^{cd}	53.79±27.33^{cd}	2.27±0.78^{a}
395077.12	6.40±0.93^{c}	48.04±24.97^{c}	1.80±0.41^{a}	7.20±1.92^{d}	50.69±27.03^{c}	1.80±0.41^{a}
57.8X59.41	2.40±0.93^{a}	30.94±16.76^{a}	3.70±1.01^{c}	2.20±1.00^{a}	34.52±17.69^{a}	3.70±1.01^{c}
59.41x220.54	8.00±1.64^{d}	51.85±26.19^{c}	1.80±0.41^{a}	7.20±1.92^{c}	57.83±27.62^{de}	1.80±0.41^{a}
CRUZA	6.40±0.93^{c}	51.92±26.25^{c}	2.27±0.78^{a}	6.53±1.46^{cd}	53.08±26.95^{c}	2.27±0.78^{a}
KIMURIX59.58	6.93±1.44^{d}	49.51±26.35^{c}	2.27±0.78^{a}	6.93±2.26^{d}	47.98±25.75^{c}	2.27±0.78^{a}
KINIGIX19.17	8.00±1.64^{d}	51.94±26.19^{c}	2.03±0.67^{a}	6.20±1.00^{cd}	52.26±27.02^{c}	2.03±0.67^{a}
NAROPOT4	8.00±1.64^{d}	50.67±24.99^{c}	2.50±0.82^{b}	7.20±1.92^{d}	51.75±26.59^{c}	2.50±0.82^{b}
NAROPOT4X38.107	8.00±1.64^{d}	55.36±26.99^{d}	2.27±0.78^{a}	7.20±1.92^{d}	57.24±27.92^{de}	2.27±0.78^{a}
NAROPOT4X77.54	8.00±1.64^{d}	53.77±26.89^{cd}	2.27±0.78^{a}	7.20±1.92^{d}	55.60±27.88^{d}	2.27±0.78^{a}
VICTORIA	5.00±0.00^{c}	41.51±21.12^{a}	2.50±0.82^{b}	4.93±0.83^{b}	41.41±19.39^{b}	2.50±0.82^{b}

Different letters imply significant differences at 5%. The differences are compared across the columns for all genotypes for both season one and season two at KAZARDI site. Variety checks (Cruza, NAROPOT4 and Victoria).

3.3.2 Determination of late blight resistance in potato genotypes

Late blight resistance was exhibited in some potato genotypes and others succumbed to the disease. The genotypes which showed much resistance and those that had less resistance were observed across the two sites and in all two seasons of the study (Season A and B 2020). The most outstanding genotypes in terms of late blight resistance were noted to be NAROPOT4x77.54, NAROPOT4x39.107 and 57.8x59.41 while the genotypes that were very susceptible to the disease were found to be Victoria, Cruza and 39366.18 (Figure 2). Late blight disease was more severe at Kalengyere site for season one and season two compared to severity levels at KaZARDI site (Figure 2 and Figure 3). It was observed that genotype Victoria was more severely affected by late blight disease across the two sites of Kalengyere and KaZARDI. The average score for disease severity during the evaluation period was 10%, and it was completed once a week, every after seven days following the initial diagnosis. A 1–9 Henfling disease estimation scale was employed, with 0 representing 0%, 1 = 10%, 3 = 10%–20%, 5 = 20–30%, 7 = 30%–60%, and 9 = 60–100%.

The overall incidence rate of late blight disease was 78%. In season two, this was realised at the Kalengyere site.

When it came to control checks, the Victoria genotype proved to be more prone to late blight disease, and 39266.18 which was a nrewly developed genotype was particularly prone to the disease. Across all sites and seasons, a broad spectrum of newly bred genotypes generally showed high levels of resistance to

the late blight disease, which had a disease severity of less than 10%.

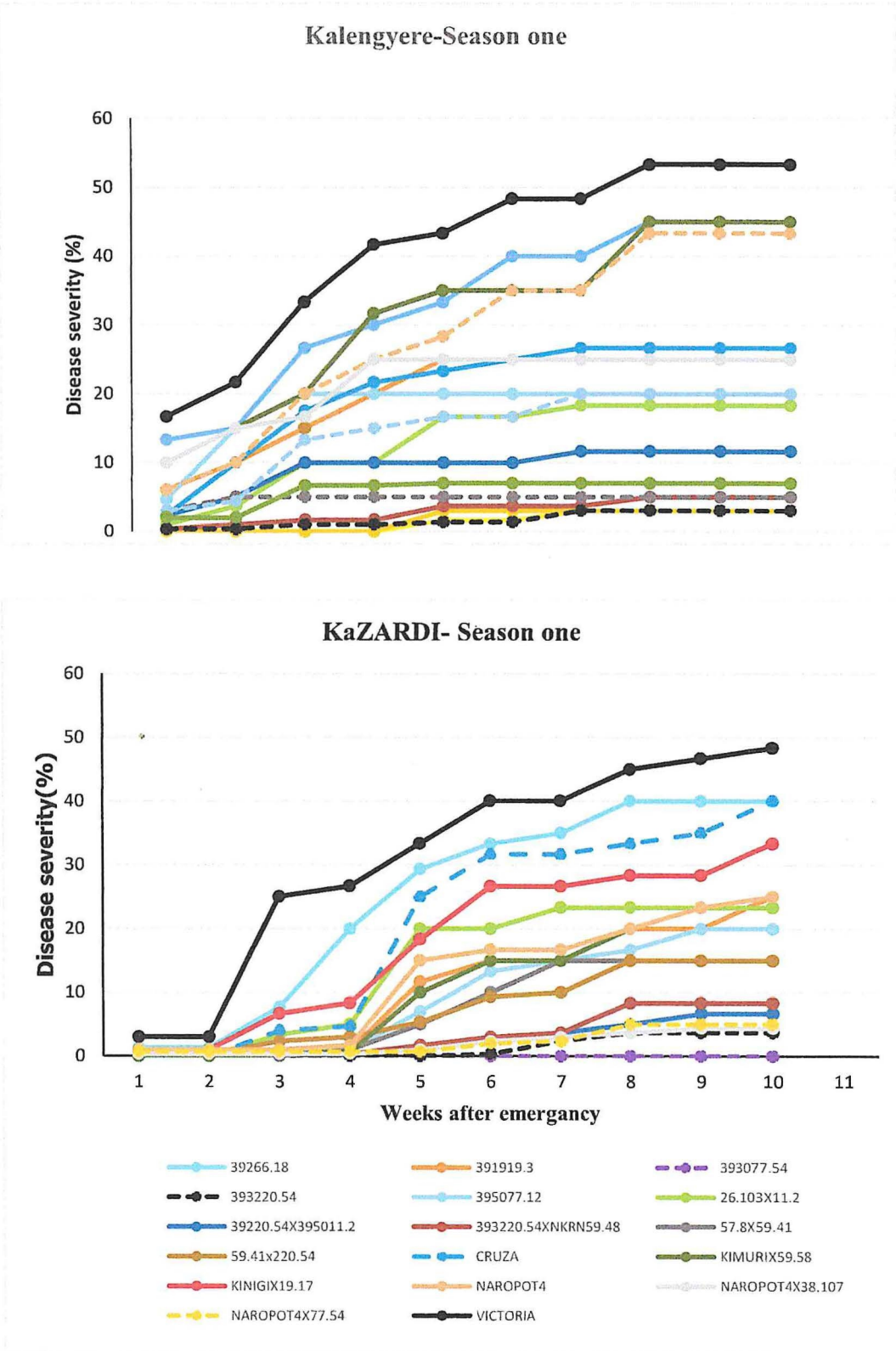

Figure 2: Late blight disease severity progress curves for two sites in season one

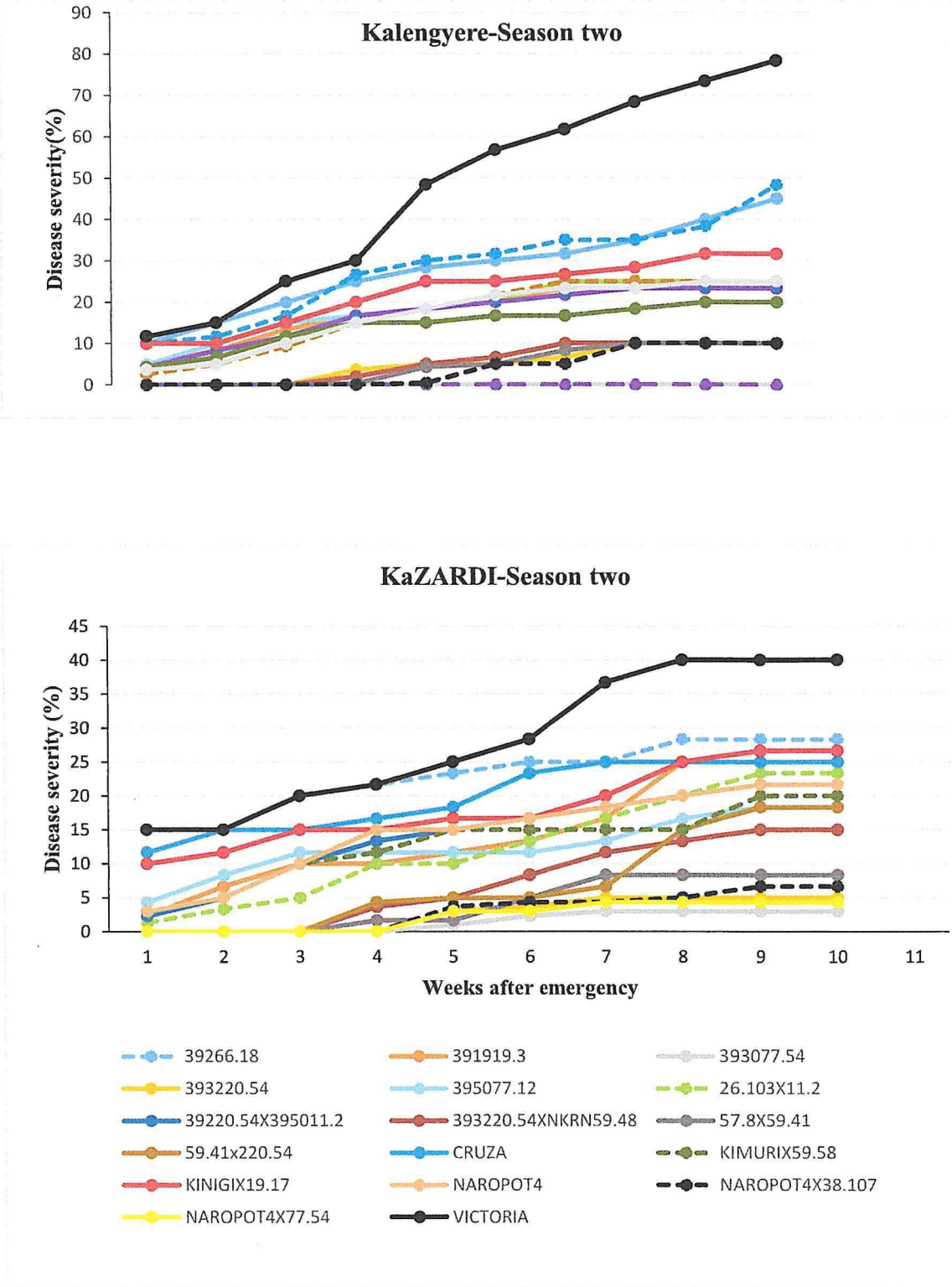

Figure 3: Late blight disease severity progress curves for two sites in season two

3.3.3 Flowering days and maturity periods among the 17 genotypes

Results indicated that genotypes to first reach 50% flowering on both the study sites of Kalengyere and KaZARDI were 391220.54x395011.2 and Victoria (Check). Genotypes which flowered late across the two sites were 26.103x11.2, Cruza, Kinigix19.17 and NAROPOT4x77.54 (Figure 4 and 5). The genotypes studied had very significant influences on flowering days and maturity duration at 1% (P<.0.01), as well as senescence or the commencement of leaf yellowing, according to the analysis of variance. Compared to Kalengyere location, the majority of genotypes flowered earlier at KaZARDI site (Figure 6). The disparity in elevation between the two locations is attributed to this.

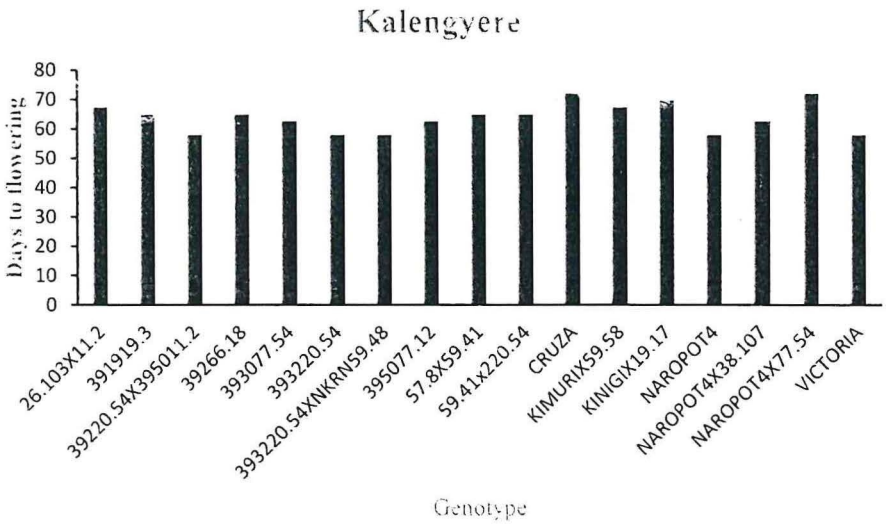

Figure 4: Days to flowering among the 17 potato genotypes at Kalengyere site

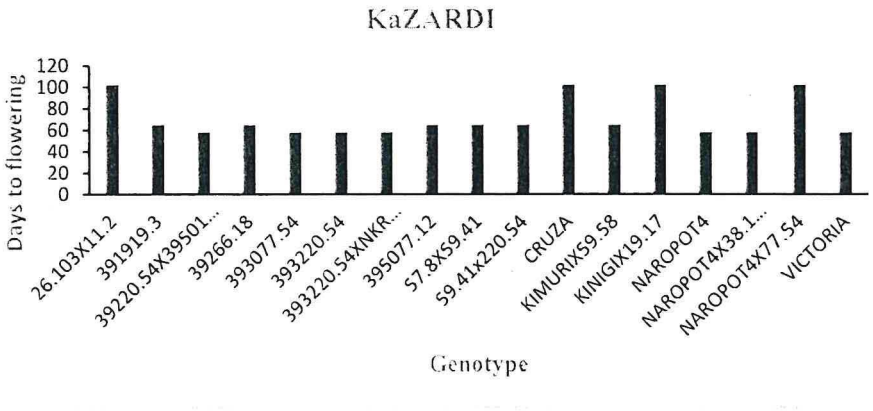

Figure 5: Days to flowering among the 17 potato genotypes at KaZARDI Site

The senescence stage of each individual genotype was scored in order to calculate the maturity duration of the potato genotypes. Senescence of potato is when the crop has attained its physiological maturity and the leaves start yellowing indicating that the crop has matured and is ready for harvesting. Genotypes that showed early maturity for two sites of Kalengyere and KaZARDI were; 39220.54x395011.2, 393220.54, 393220.54xNKRN59.48, NAROPOT4 and Victoria. These genotypes showed early maturity across the two sites but genotypes at KaZARDI site matured earlier than at Kalengyere site. The resources available in a particular environment to enable optimal plant growth and yield can be used to explain a crop's yield in any given environment (Bidinger *et al.*, 1996).

Potato genotypes that were found to be late maturing in all the two study sites were NAROPOT4x77.54, Kinigix19.17, Cruza and 26.10311.2 after attaining more days than the rest to reach their senescence stage (Figure 6 and 7).

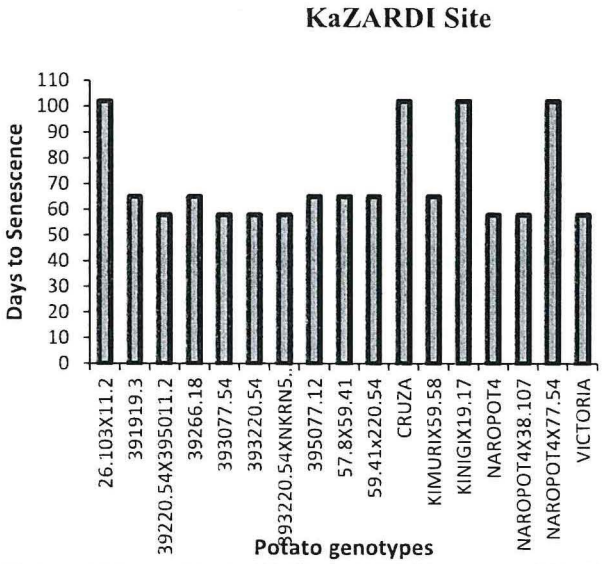

Figure 6: Days to Senescence among the 17 potato genotypes at KaZARDI Site

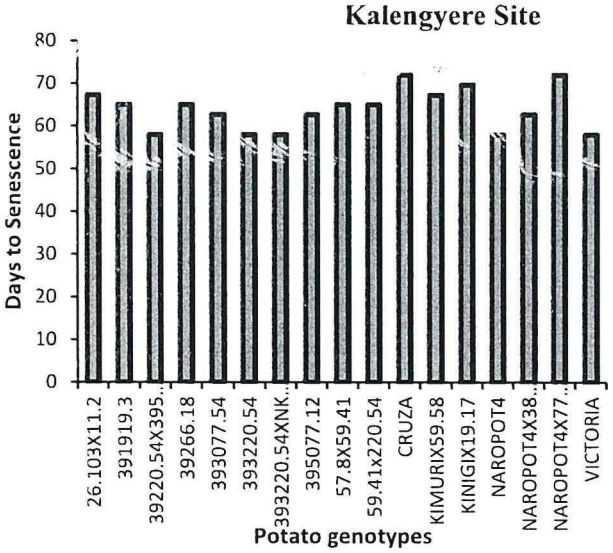

Figure 7: Days to senescence among the 17 potato genotypes at Kalengyere site

3.4 Discussion

The performance of the seventeen potato genotypes under study differed in terms of agronomic parameters, and they were described at two distinct altitudes: 2450 m.a.s.l for the Kalengyere site and 2200 m.a.s.l for the KaZARDI site. Season one and season two plant vigor and height at the Kalengyere location differed significantly ($P<0.01$), according to analysis of variance. The genotype performace at the Kalengyere location for season one and season two did not differ significantly ($P>0.05$) based on the number of stems per plant (Table 2 A). At KaZARDI site, there was also significant difference in genotype performance in regard to plant vigor and average plant height ($P<0.01$) for both season one and season two (Table 2 B). The number of stems for genotypes investigated in seasons one and two did not change significantly ($P>0.05$). The study found out that the potato genotypes at Kalengyere site exhibited better growth traits compared to the KaZARDI site. This is explained by the fact that Kalengyere site is situated on a higher altitude, with volcanic soils and cool temperatures compared to KaZARDI site which is slightly on a lower altitude, with sandy loam soil and with slightly warmer temperatures. This finding is consistent with other research that demonstrated how environmental factors like soil type and climate can affect plant growth and yield (Figueroa-López *et al.*, 2016). Different environmental conditions affect crops in different ways, and these elements are all encountered during the crop-producing process for example altitude, temperature, amount of water in the soil, atmosphere pollutants, light, soil stresses such as salinity, acidity and mineral deficiency (Bhadra *et al.*, 2022). The study to determine the potato late blight resistance among the seventeen

genotypes in all the two sites of the study was done between the first and second seasons (March-July) and (September-December) 2020. The study revealed that the presence of late blight disease was influenced by environment and genetic make up of genotypes. The disease severity varied among the test genotypes and sites with Kalengyere showing higher severity than KaZARDI in the first season. This finding aligns with previous studies that have identified variations in late blight resistance among potato genotypes (Fry *et al.*, 2015). For all the two study sites, most genotypes showed signs of late blight within the first four weeks after germination, while some genotypes remained asymptomatic until the 6^{th} week and beyond. Genotypes that showed high level of resitance in all the two sites are; NAROPOT4x77.54, NAROPOT4x39.107 and 57.8x59.41. This suggests differences in disease susceptibility and latency periods among the genotypes. Late blight is known for its ability to rapidly spread and infect potato plants under favorable environmental conditions (Fry *et al.*, 2015). It is noteworthy that the severity of the late blight disease can be impacted by a number of variables, including genetic resistance, environmental factors, and management techniques. Further research is needed to determine the specific genes and mechanisms involved in late blight resistance and to develop strategies for breeding and managing potato genotypes with improved resistance to the disease.

On maturity period, all the seventeen potato genotypes responded differently in all the two sites and in both season one and season two (March-July) and (September-December) 2020. For genotypes, environments, and genotype by environment interaction, highly significant differences ($P<0.01$) were noted. This showed that genotypes performed differently in terms of maturity

depending on the location. This tells us that genotypes could be chosen based on specific environment (Zhao & Shizhong, 2012). The differences noted could probably be attributed to the differences in the conditions in given environments. This relates to the research conducted by Nakitandwe *et al.*, (2003) who likewise obtained comparable outcomes. This suggests that a genotype's growth maturity may be impacted by the genotype, altitude, and additional environmental variables. Potato genotypes began flowering earlier during the second rainy season of 2020 (September–December) than during the first rainy season (March–June), according to an assessment of genotype, location, and cropping season means. Across locations and seasons, genotype Kinigix19.17, Cruza, 57.8x59.41, NAROPOT4x77.54 and 26.103x11.2 were the earliest to flower and genotypes 39220.54x395011.2, 393077.54 and 393220.54 took long to flower. On average, genotypes flowered earlier in KaZARDI than Kalengyere (Figure 5). Genotypes Kinigix19.17 consistently started flowering earlier than any genotype across locations and seasons.

3.5 Conclusion

Based on the results from the study, Kalengyere site generally exhibited better growth traits compared to the KaZARDI site. Regarding favorable agronomic features, such as average plant height and plant vigor, the study found that there were highly significant differences ($P<0.01$). For all the two sites and both seasons of the sudy, there was no significant difference ($P>0.05$) in the number of stems per plant across the seventeen genotype. Genotypes which showed outstanding favourable growth traits were found to be 393077.54, 59.41x220.54, NAROPOT4x38.107, NAROPOT4x77.54, 395077.54, and NAROPOT4 which were newly bred genotypes except NAROPOT4 which was

(Variety check). Genotype which had poor growth traits across locations and seasons was found to be 57.8x59.41.

The study revealed that the presence of late blight disease can also be influenced by the environment. The disease severity varied among the test genotypes and sites with Kalengyere site showing higher severity than KaZARDI site. Genotypes NAROPOT4x77.54, NAROPOT4x39.107 and 57.8x59.41 were a symptomatic up to 6th week. Genotypes, such as Victoria, Cruza and 39366.18 were severely affected by late blight disease and the symptoms would show within the first four weeks after germination. This finding aligns with previous studies that have identified variations in late blight resistance among potato genotypes (Fry *et al.*, 2015). Potato genotypes began flowering earlier during the second rainy season of 2020 (September–December) than during the first rainy season of 2020 (March–June), according to an assessment of genotype, location, and cropping season means. In terms of locations and seasons, the genotypes Kinigix19.17, Cruza, 57.859.41, NAROPOT4x77.54, and 26.103x11.2 were the first to flower, whereas the genotypes 39220.54x395011.2, 393077.54, and 393220.54 were the last to commence flower buds.

Regarding senescence or maturity duration, genotypes 393220.54xNKRN59.48, NAROPOT4, 393220.54 and Victoria attained their senescence period earlier compared to other genotypes with genotypes reaching the senescence earlier at KaZARDI site (Figure 6) and later on Kalengyere site (Figure 7). The study concluded by showing that the genotypes of potatoes that were evaluated varied in terms of flowering days and maturity time depending on the location. These variations highlight the genetic diversity and adaptability

of the genotypes, which can be important factors to consider in potato breeding programs and crop management practices. The statistical analysis indicated significant genotype effects on these traits, emphasizing the role of genotype selection for desired flowering and maturity characteristics.

CHAPTER FOUR

DETERMINING TUBER MORPHOLOGICAL TRAITS AND YIELD OF THE NEWLY BRED POTATO GENOTYPES AT DIFFERENT ALTITUDES IN THE KIGEZI HIGHLANDS

4.1 Introduction

Multi-location trials, also known as multiple trials, are frequently conducted to confirm genotype performance for important traits and evaluate the stability or generalizability of genotype performance that has shown promise in on-station testing. The overall effectiveness of additive main effects and multiplicative interaction (AMMI) analysis across many sites, as well as genotype by environment (G x E) interactions, can be obtained from multi-location trials (Varela *et al.*, 2006). The breeding process is influenced by the strength of G x E interactions, which also aid in identifying and selecting superior genotypes.

In this research, G x E interactions for 17 potato genotypes were examined in two different environments over the course of two wet seasons.

Long-term droughts and high temperatures are detrimental to potato bulking, according to research by Abalo *et al.* (2003). The growth of tubers slows down with increasing soil temperature and eventually stops completely above 30° C.

In light of the increasing unpredictability of climate and environmental conditions, there is a pressing need to prioritize the breeding of resilient potato varieties. This will ensure the sustainability of potato production by enabling the crop to withstand varying weather patterns. This study's main goal was to evaluate the yield performance and stability of various potato genotypes in the Kigezi highlands at varying elevations (G x E). Finding genotypes with

advantageous physical traits and assessing their influence on yield measures were the main objectives of the evaluation.

4.2 Materials and Methods

4.2.1 Experimental sites

In this study, G x E interactions for 17 potato genotypes were examined in two different environments over the course of two wet seasons. Two experimental sites were chosen as they are situated on different altitudes hence different bi-modal rainfall and different soil parterns for stability studies.

After bush clearing and land openings (both primary and secondary cultivation), agronomic practices (irrigation, fertilization, weed control and plant protection) were conducted. Each plot had 10 tubers whereby in each row there were five tubers planted. Number of seed tubers used in first season per plot were 10 as the planting materials were few but were increased to 30 tubers in the second season as they had been multiplied in the first season of the experiment. Seed tubers in each row were planted at 30cm apart and 75cm from one row to another with the separation of 1m from one plot to another.

A single experiment with three replications and a fully randomized block design was conducted at each site. Compound NPK 17:17:17 fertilizer was applied at a rate of 2 to 4 pounds (0.9 to 1.8 kilograms) per 1,000 square feet (93 square meters) of soil in order to promote vigor and tuberization.

The first set of fertilizer was applied at planting in furrows and well mixed with soil before seed tubers were put in the soil. To encourage the growth of flowers and vegetative growth, a top-dressing of the second batch of fertilizer was applied 40 days after planting. After forty and fifty days, respectively, weeding

and earthing up were completed. Harvesting took place 14 days after cutting (dehaulming), and the crop was cut 110 days after planting.

4.2.2 Potato genotypes used in the study

The freshly bred germplasm that was being maintained as tiny tubers (first tuber generation) at KaZARDI was used to select the experimental potato genotypes. This study used 17 potato genotypes altogether. Fourteen (14) newly bred potato genotypes were compared with three commercial varieties (Victoria, NAROPOT4, and Cruza).

4.2.3 Experimental designs

Utilizing three replications of a randomized complete block design (RCBD) , 17 potato genotypes occupying 17 plots each of 1.5m X 1.5m were made within the experimental fields at KaZARDI and Kalengyere satellite station for the first season (March-June 2020 season A). Every plot was made up of two rows that were one meter apart. The seed tubers were spaced 30 cm within the row and 75cm between the rows (30cm x 75cm) and the inter-plot spacing was 1m. Five tuber seeds were used per row. Ten tuber seeds of each potato genotype were planted per replicated plot. Excavating trenches that were 10 cm deep and in a straight line, followed by the hand application of 120 kg of NPK 17:17:17 fertilizer, sprouting tubers were planted in the trenches with their sprouts pointing upwards, and the trenches were covered to form a mound on the tuber seeds. This was repeated in the second season (September-December 2020 Season B) but the number of tubers used per plot increased to 30 tubers where 10 tubers were planted in each row making 3 rows per plot with the spacing of

(30cm x 75cm) with a separation of 1m from one plot to another for 3 replications. The size of the plot also increased from 1.5m to 3m in width x 2.25m in length. The planting of the experiment was done early in the season for both two sites to utilize the first rains and allow good germination of the potato. Five tuber seeds were planted in furrows with fertilizer in each row and 10 tubers for each plot. Ten tubers were planted in each plot since, during the first growing season, there were not enough tubers available from the germplasm that was kept at the research station for use in the experiment. In the second season, three rows of ten tubers each were planted, increasing the total number of tubers planted each plot from ten to thirty. Because they had been produced from the first season of the experiment, more tubers were planted in each plot during the second season.

4.2.4 Data collection methods

4.2.4.1 Determining morphological attributes of test genotypes

Seventeen potato genotypes, majority being the newly bred genotypes and the commercial varieties which are commonly grown by farmers (Victoria, NAROPOT4 and Cruza) acted as checks. The freshly produced genotypes and variety checks were acquired from the Kachwekano Zonal Agricultural Research and Development Institute (KaZARDI) located in Kabale, South-Western Uganda. Good agronomic practices (GAP) were used in the cultivation of the potatoes harvested at their physiological maturity and different morphological attributes were recorded accordingly as guided by (Kajunju *et al.*, 2022). Traits for skin colours and tuber flesh colourrs were evaluated visually using a sample of 4 tubers per genotype and from each plot

in each of the three replications making at toal of 24 tuber samples. These 4 tubers were cut from each genotype to assess flesh colour by using a 1–6 scale (Domański *et al.*, 2004). This process was carried out for two study seasons (March–July and September–December 2020) at KaZARDI and Kalengyere. In the first and second seasons of 2020, measurements of the eye depth and tuber shape were also made. Tuber shapes were scored in three categories as oval, round and oblong; and for eye depth as surface, intermediate and deep. Eye depth was evaluated on 1–9 scale, where 1 = eyes deeper than 5 mm, 9 = eyes not perceivable by touch (Domański *et al.*, 2004)

Plate 2: Morphological appearances of genotypes 59.41x220.54 and 393220.54

4.2.4.2 Determination of genotype yield stability

Yield data were collected at harvest. All tubers were grouped into three categories at harvest, that is small tubers, medium tubers and large tubers. Each category's weights and quantities of tubers were noted. Commercial tubers/large tubers or those measuring more than 60 mm were classified as falling under Category I; commercial tubers/medium tubers measuring between 30 and 60 mm were classified as falling under Category II; and non-commercial/small

tubers or those measuring less than 30 mm were classified as falling under Category III (Plate 3) (Ghislain *et al.*, 2019).

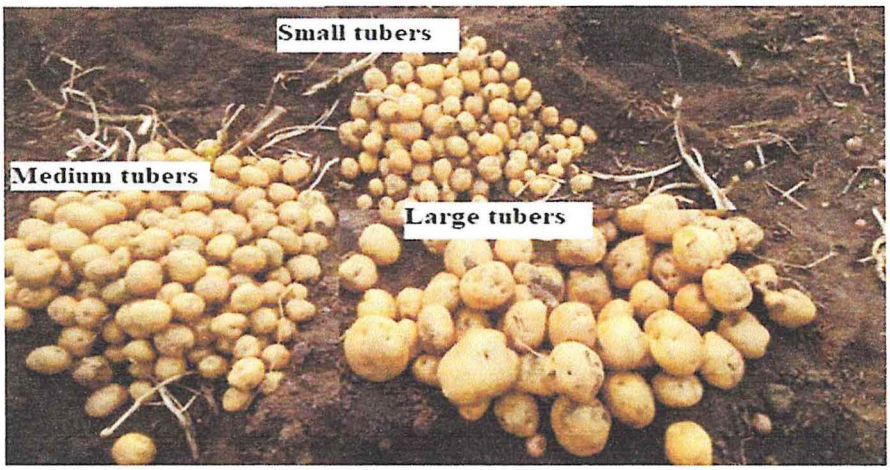

Plate 3: Potato tuber of genotype 395077.12 in three grades

At harvest, data collection was done on individual plants. Data for yield parameters, such as total weight for commercial weight (Figure 4), were expressed in tons/ha (Kesiime *et al.*, 2016).

Plate 4: Weighing of potato tubers per plant using a digital scale at harvesting

4.2.5 Magnitude of genotype by environment (G x E) interaction on yield performances

At each of the two sites, the study was carried out over the course of two seasons using a randomized complete block design (RCBD). In 2020, during the first and second rainy seasons, three replications were employed for each site. Each genotype was planted in a ridge using a 30-by-75-cm furrow spacing. Every genotype was planted in two rows, with five tubers planted in each row, for a total of ten tubers per plot. After harvesting the first season, when I had less planting tubers, I planted more tubers in the second season, increasing the number of tubers planted per row from five to ten. Each plot had three rows planted with ten tubers and making a plot of 30 tubers with the spacing of 30cm x 75cm. Each plot was separated by a space of 1m from one plot to another.

4.3 Statistical analysis

The Residual Maximum Likelihood of breeding View tool in Genstat 19th edition was utilized to analyze the variations in genotype yield between the KaZARDI and Kalengyere sites. The least significant difference ((LSD) was used to distinguish between genotype mean yields at 5% level of significance. The G x E interactions were examined using Additive Main Effects and Multiplicative Interaction (AMMI), which employs standard analysis of variance and principle component analysis (PCA) to identify patterns in the data (Gauch, 2006; Yan *et al.*, 2007). The AMMI method helps to improve the accuracy of the statistical analysis by describing the interactions that genotypes have with each environment and capturing their true structure. The data set for Kalengyere was more affected by the number of plants harvested, the weight of

small tubers, the number of small tubers, and the weight and number of large tubers, as indicated by the coefficients of the highest weights in the components PCA loading at ≥0.5. In contrast, the largest weights of the coefficients in the components PCA loading at ≥0.5 were seen for KaZARDI in terms of number of medium tubers, weight of medium tubers, number of big tubers, weight of big tubers, number of rotten tubers, and weight of rotten tubers (Byarugaba *et al.*, 2021). The genetic stability of the variations was evaluated using the following AMMI model equation.

$Y_{ijk}=M+B/E_{jk}+G_i+GE_{ij}+E_{ijk}$

Where Y_{ijk} represents the $_{ith}$ genotype in the $_{jth}$ environment and $_{kth}$

Block; M denotes the overall mean; $\frac{B}{E_{jk}}$ corresponds to the block within

The $_{jth}$ environment and in the $_{kth}$ block, G_i is the effect of the $_{jth}$

Genotype; E represents the effect of the jth environment; GE_{ij} is the effect of

Interaction of the $_{ith}$ genotypes with the $_{jth}$ environment and $_{ijk}$ is

The effect of experimental error

4.4 Results

4.4.1 Morphological attributes of test genotypes

Most of the potato genotypes in the study had one specific skin colour apart from genotypes 26.103x11.2 (Creamish purple), 39220.54x395011.2 (Creamish red), 393077.54 (Creamish red), 393220.54 (Creamish red) and Cruza (Creamish purple). Different potato genotypes had one flesh color apart from genotypes Kinigix19.17 (Creamish purple), Cruza (Creamish purple), and 391919.3 (Creamish purple) which had two different flesh colours). Genotypes had specific tuber shapes ranging from round, oval to oblong. Genotypes which were found to have round tuber shapes included;

26.103x11.2, 57.8x59.41, 59.41x220.54, Cruza, Kimurix59.58, NAROPOT4 and Victoria. Genotypes 391919.3, 39266.18, Kinigix19.17 and NAROPOT4x77.54 were found with oval tuber shape. Genotypes that were found with oblong shape included; 39220.54x395011.2, 393077.54, 393220.54, 393220.54xNKRN59.48, 395077.12, and NAROPOT4x38.107. Potato genotypes which had shallow eye depth included; 26.103x11.2, 391919.3, 39220.54x395011.2, 39266.18, 393220.54, 393220.54xNKRN59.48, 57.8x59.41, 59.41x220.54, Cruza, NAROPOT4x38.107, NAROPOT4x77.54. Genotypes with intermediate or medium eye depth were found to be; 393077.54, 395077.12, Kimurix59.58, Kinigix19.17, NAROPOT4 and Victoria (Table 3). The findings indicated that there was no significant difference ($P>0.05$) between the genotypes for the KaZARDI and Kalengyere locations with regard to skin colour, flesh colour, tuber form, and eye depth.

Table 3: Morphological attributes of potato genotypes for Kachwekano Zonal Agricultural Research and Development Institute and Kalengyere

Genotypes	Skin colour	Flesh colour	Shape	Eye depth
26.103x11.2	Creamish purple	Cream	Round	Shallow
391919.3	Purple	Creamish Purple	Oval	Shallow
39220.54x395011.2	Creamish red	Cream	Oblong	Shallow
39266.18	Red	White	Oval	Shallow
393077.54	Creamish red	Cream	Oblong	Intermediate
393220.54	Creamish red	cream	Oblong	Shallow
393220.54xNKRN59.48	Red	Cream	Oblong	Shallow
395077.12	Cream	White	Oblong	Intermediate
57.8x59.41	Red	Cream	Round	Shallow
59.41x220.54	Red	Cream	Round	Shallow
Cruza	Creamish purple	Creamish purple	Round	Shallow
Kimurix59.58	Cream	Cream	Round	Intermediate

Kinigix19.17	Purple	Creamish purple	Oval	Intermediate
NAROPOT4	Red	Cream	Round	Intermediate
NAROPOT4x38.107	Red	Cream	Oblong	Shallow
NAROPOT4x77.54	Red	Cream	Oval	Shallow
Victoria	Red	White	Round	Intermediate

4.4.2 Genotype yield stability

Genetic combinations and environmental factors were shown to be highly significant ($P<0.01$) in the findings of the analysis of variance (ANOVA), indicating that various genotypes responded differently to the experimental settings. ANOVA by AMMI results were used to categorize the main effects of treatments into genotype, environment, and genotype x environment (G x E) interactions (Table 4). Additionally, the results demonstrated that the first interaction principal component axis (IPCA 1) was highly significant P (<0.01) at (50.1%) in explaining the interaction, accounting for 37.9% of the interaction for KaZARDI and 37.9% for the Kalengyere site. In comparison, only 27.4% of the interaction was described by IPCA 2. According to the IPCA scores and means of 17 genotypes in two scenarios, many genotypes were highly interacting. The most productive genotypes were; 391919.3, 59.41 x220.54, 393220.54x395011.2, 393077.54, 26.103x11.2, Kinigix19.17, NAROPOT4x77.54 and NOROPOT4x39.107 and the lowest performing genotypes were; 57.8x59.41 and Victoria. The most interactive genotype based on the first IPCA were Kinigix19.17, Cruza, 39220.54x395011.2, 26.103x11.2, Kimurix59.58, 393220.54 and 391919.3 while the least interactive genotype were 59.41x220.54, 57.8x59.41 and 39266.18. Kalengyere demonstrated the highest interactive performance with respect to IPCA, followed by KaZARDI, indicating significant interactivity within the environments. The bi-plot also

indicated that KaZARDI had high Eigenvalues and was therefore, a highly interactive environment. High Eigenvalues indicated that Kalengyere was the least interacting environment. Ranking of genotypes in various environments indicated that 391919.3, 59.41x220.54, 393220.54x395011.2, 393077.54, 26.103x11.2, Kinigix19.17, NAROPOT4x77.54 and NOROPOT4x39.107 were the best in the two environments.

Table 4: Analysis of variance for additive main effects and multiplicative interaction model based on yield across two sites for two seasons

Source-Represents source of variation, DF-Represents degree of freedom, SS-Represents

Source	DF	SS	MS	F	Prob (P=0.005)
Total	203	19112	94.2	*	*
Treatments	33	8692	263.4	4.22	0
Genotypes	17	4900	306.2	4.90	0
Environments	2	2189	2188.7	174.66	0.17903
Block	4	50	12.5	0.20	0
Interactions	16	1603	100.2	1.60	0.00291
IPCA	16	1603	100.2	1.60	0
IPCA	14	0	0.0	0.00	0.21295
Residuals	14	0	0.0	0.00	0.83664
Error	166	10370	62.5	*	*

sums of squares, MS- Represents mean square, F-Represents F-value and P-Represents P-value.

At the 5% level of significance, genotype mean yields were distinguished using the least significant difference (LSD). Potato genotypes had a substantial influence ($P<0.05$) on the genotype mean, first interaction principle component axis, and second interaction principle component axis, according to an analysis of variance. Genotypes 59.41x220.54, 59.41x220.54, 391919.3 and

NAROPOT4 (Variety check) were found with highest means thus indicating high yields with marketable sized tubers (Table 5).

Table 5: Genotype means on marketable yield and interaction principal component analysis scores

Genotype	NG	GM	IPCAg[1]	IPCAg[2]
26.103x11.2	1	18.78	0.24700	0.00000
391919.3	2	27.07	0.83142	0.00000
39220.54x395011.2	3	18.98	0.22660	0.00000
39266.18	4	15.46	0.03743	0.00000
393077.54	5	23.36	0.21873	0.00000
393220.54	6	22.05	0.77545	0.00000
393220.54xNKRN59.48	7	21.28	-0.61898	0.00000
395077.12	8	20.51	0.97366	0.00000
57.8x59.41	9	15.02	-0.15466	0.00000
59.41x220.54	10	34.84	-0.17739	0.00000
Cruza	11	19.18	-0.00250	0.00000
Kimurix59.58	12	18.51	-0.67057	0.00000
Kinigix19.17	13	19.00	0.36447	0.00000
NAROPOT4	14	25.98	0.74835	0.00000
NAROPOT4x38.107	15	28.65	1.40038	0.00000
NAROPOT4x77.54	16	24.23	-1.20922	0.00000
Victoria	17	19.16	-2.99016	0.00000

NG-represents number of genotypes, GM- Represents genotype mean, IPCAg(1)-Represents first interaction principal component axis for genotype. IPCAg(2)-Represents second interaction principal component axis for genotype.

Genotypes 57.8x59.41, 39266.18 and Victoria were found more stable than among the seventeen potato genotypes tested. In regard to static stability, genotypes 395077.12, 391919.3 and 329320.54 were found more stable (Table 6).

Table 6: Stability of superiority measures coefficients

Genotype	Stability superioritymeasures coefficients Values	Static stability measure coefficients values	Wricke's ecovalence stability coefficients
59.41x220.54	0.0	15.33	0.51
NAROPOT4x38.107	29.3	58.64	32.06
391919.3	34.4	63.90	11.30
NAROPOT4	42.7	58.64	9.16
NAROPOT4x77.54	60.7	0.07	23.90
393077.54	66.5	30.43	0.78
329320.54	85.6	60.34	9.83
393220.54xNKRN59.48	92.8	4.54	6.26
395077.12	108.1	73.43	15.50
Cruza	122.8	21.36	0.00
39220.54x395011.2	126.5	30.79	0.84
Kinigix19.17	126.7	37.28	2.17
26.103x11.2	129.8	31.71	1.00
Kimurix59.58	134.4	3.69	7.35
Victoria	155.3	55.62	146.16
39266.18	188.1	22.88	0.02
57.8x59.41	196.4	16.06	0.39

AMMI- estimates showed that genotypes 59.41x220.54, NAROPOT4x38.107 and 391919.3 were ranked the best at Kalengyere site while genotpes Victoria, 57.8x59.41, and 39266.18 were ranked least at Kalengyere site (Table 7). The variance of ranks revealed no significant difference (P>0.5) between the top three genotypes. Similarly, no significant difference was found between the three genotypes that were ranked lowest (P>0.05). Nonetheless, a highly

significant difference (P<0.01) was seen between the genotypes with the highest ranking and the genotypes with the lowest ranking at the Kalengyere site.

Table 7: Additive main effects and multiplicative interaction estimates per environment-Kalengyere

Genotype	Estimates	Ranked	Variance of Ranks
26.103x11.2	22.76	59.41x220.54	37.61
391919.3	32.72	NAROPOT4x38.107	35.93
39220.54x395011.2	22.90	391919.3	32.72
39266.18	18.84	NAROPOT4	31.40
393077.54	27.26	393220.54	27.54
393220.54	27.54	393077.54	27.26
393220.54xNKRN59.48	22.78	395077.12	26.57
395077.12	26.57	NAROPOT4x77.54	24.05
57.8x59.41	17.86	Kinigix19.17	23.31
59.41x220.54	37.61	39220.54x395011.2	22.90
Cruza	22.44	93220.54xNKRN59.48	22.78
Kimurix59.58	19.87	26.103x11.2	22.76
Kinigix19.17	23.31	Cruza	22.44
NAROPOT4	31.40	Kimurix59.58	19.87
NAROPOT4x38.107	35.93	39266.18	18.84
NAROPOT4x77.54	24.05	57.8x59.41	17.86
Victoria	13.89	Victoria	13.89

Using the additive mean effects and multiplicative interactions (AMMI) model, the G x E interaction was investigated further. Extremely large variations in genotype performances were revealed by AMMI analysis for tuber yield across settings. This demonstrated that the genotypes' responses differed depending on the environment. With highly significant variations between each component, the analysis of variance results partitioned the major effect treatments into

genotype (G), environment (E), and G x E interactions. Additionally, it divided the G x E interaction effects into principle components, with IPCA-I and IPCA-II accounting for the very significant G x E interactions. At KaZARDI site, AMMI- estimates showed that genotypes 59.41x220.54, Victoria and NAROPOT4x77.54 were ranked the best while genotypes 39266.18, 57.8x59.41 and 395077.12 were ranked the least (Table 8).

Table 8: Additive main effects and multiplicative interaction estimates per environment Kachwekano Zonal Agricultural Research and Development Institute

Genotype	Estimates	Ranked	Variance of Ranks
26.103x11.2	14.79	59.41x220.54	32.07
391919.3	21.41	Victoria	24.44
39220.54x395011.2	15.06	NAROPOT4x77.54	24.41
39266.18	12.07	391919.3	21.41
393077.54	19.46	NAROPOT4x38.107	21.37
393220.54	16.55	NAROPOT4	20.57
393220.54xNKRN59.48	19.77	393220.54xNKRN59.48	19.77
395077.12	14.45	393077.54	19.46
57.8x59.41	12.19	Kimurix59.58	17.15
59.41x220.54	32.07	393220.54	16.55
Cruza	15.91	Cruza	15.91
Kimurix59.58	17.15	39220.54x395011.2	15.06
Kinigix19.17	14.68	26.103x11.2	14.79
NAROPOT4	20.57	Kinigix19.17	14.68
NAROPOT4x38.107	21.37	395077.12	14.45
NAROPOT4x77.54	24.41	57.8x59.41	12.19
Victoria	24.44	39266.18	12.07

The bi-plot shows that Kinigix19.17 and 39220.54x395011.2 had IPCA scores approximately equal to zero. Cruza, 393220.5xNKRN59.48, 391919.3, and NAROPOT4 also did not vary significantly at Kalengyere site (Figure 8) .

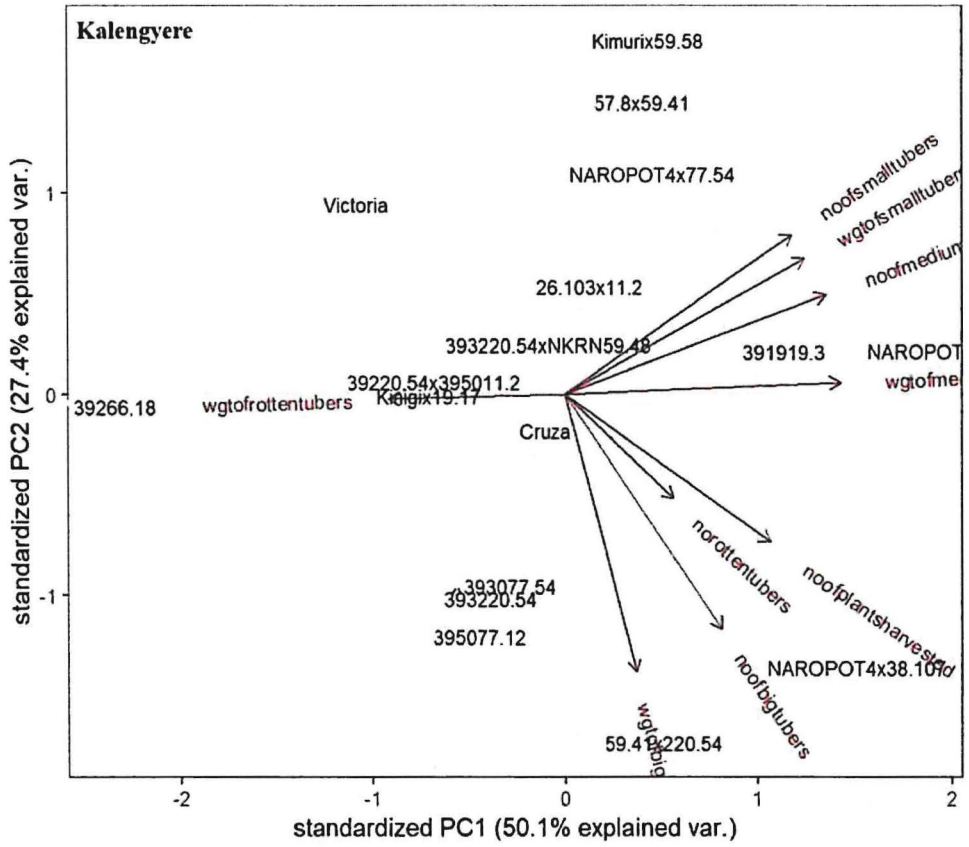

Figure 8: Interaction principle component analysis for Kalengyere site

Similary at KaZARDI, bi-plot shows that Kinigix19.17, Cruza, 39220.54395011.2, 26.103x11.2, Kimurix59.58, 393220.54, and 391919.3 had IPCA scores of approximately equal to zero. The rest of the genotypes also did not vary significantly at the Kachwekano site apart from genotypes 59.41x220.54, 57.8x59.41 and 39266.18 which showed significant levels in tuber sizes among the characterized potato genotypes (Figure 9).

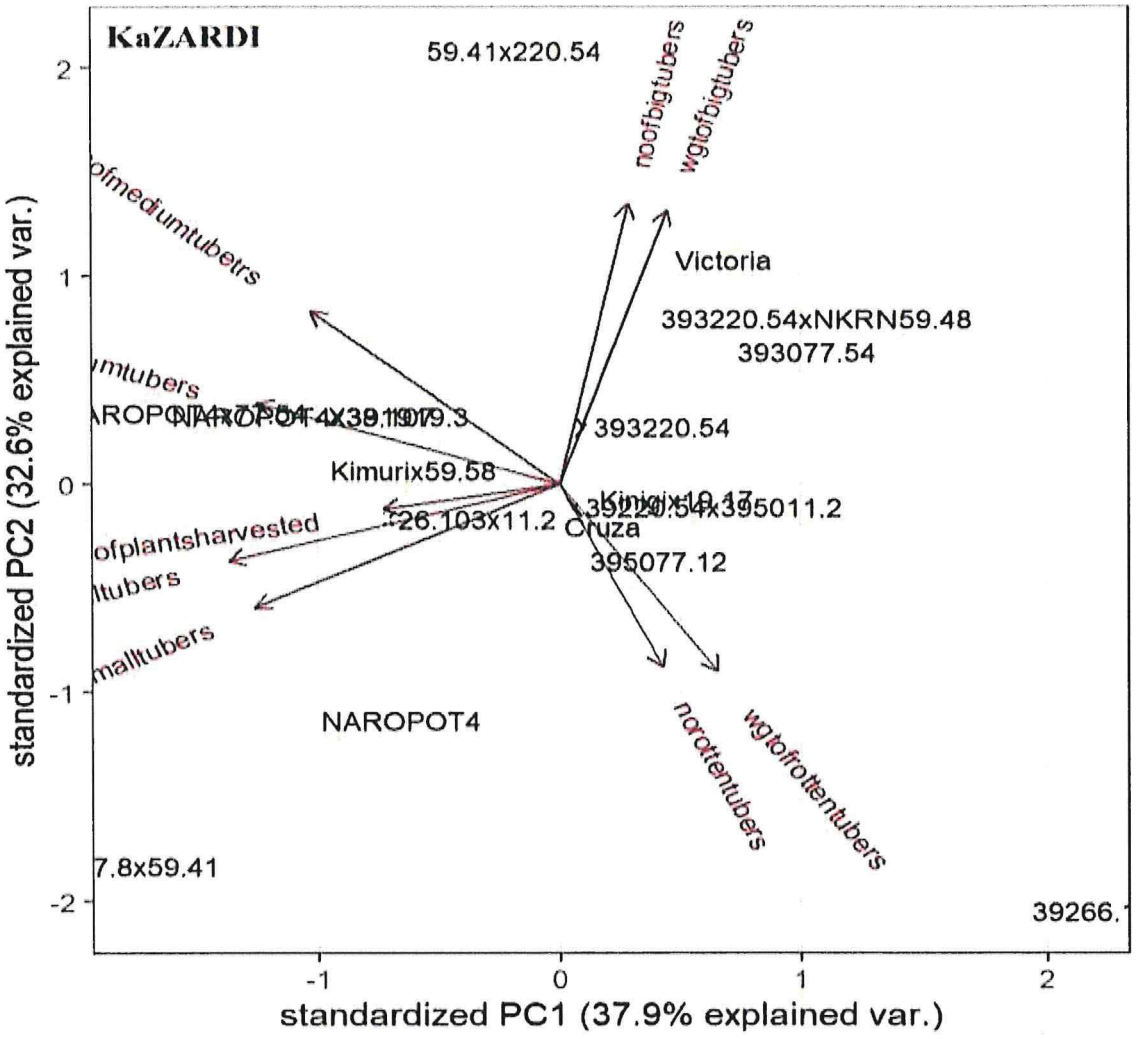

Figure 9: Interaction principle component analysis for KaZARDI site

4.4.3 Magnitude of genotype by environment (G x E) interaction on yield performances at Kalengyere and KAZARDI

The potato genotype which was outstanding in yield performance at Kalengyere in season one was 59.41x220.54. Genotypes 391919.3, 39220.54x395011.2, 393077.54, 395077.12, NAROPOT4, NAROPOT4x38.107, and NAROPOT4x77.54 were high yielding and not significantly different for Kalengyere site but significantly different for KaZARDI in season one (Table

9) Yield performances of genotypes across the two sites for two seasons were presented in form of bar graphs (Figure 10).

Table 9: Results of extracted components and scores of th coefficient variables performed by principal component analysis

	Kalengyere				KaZARDI				All combined			
Variable	Component weights											
	PC1	PC2	PC3	PC4	PC1	PC2	PC3	PC4	PC1	PC2	PC3	PC4
Eigenvalues	1.57	1.4	1.05	1.03	1.61	1.42	1.28	1.17	1.54	1.41	1.14	1.00
Proportion of Variance	0.27	0.22	0.12	0.12	0.29	0.22	0.18	0.15	0.26	0.22	0.14	0.11
Cumulative Proportion	0.27	0.49	0.62	0.73	0.29	0.51	0.69	0.85	0.26	0.48	0.63	0.74
Number of plants harvested	0.03	0.18	-0.03	0.73	0.27	0	0.27	0.33	0.22	0.13	-0.35	0.19
Number of small tubers	-0.49	0.06	0.48	-0.1	-0.35	0.28	-0.19	-0.36	-0.42	0.24	0.45	0.06
Weight of small tubers	-0.46	0.07	0.55	0.1	-0.38	0.28	-0.22	-0.4	-0.43	0.22	0.46	0.06
Number of medium tubers	-0.52	-0.11	-0.45	-0.08	-0.44	0.14	-0.03	0.54	-0.52	0.01	-0.46	-0.10
Weight of medium tubers	-0.5	-0.15	-0.47	0.05	-0.46	0.12	-0.07	0.5	-0.52	-0.04	-0.45	-0.08
Number of big tubers	0.05	-0.67	0.12	0.09	-0.15	-0.59	-0.32	0	-0.11	-0.65	0.13	0.09
Weight of big tubers	0.09	-0.66	0.15	0.13	-0.15	-0.59	-0.33	0	-0.09	-0.66	0.14	0.08
Number of rotten tubers	0.02	-0.14	0.04	-0.5	0.33	0.23	-0.55	0.17	-0.01	-0.12	0.06	-0.84
Weight of rotten tubers	0.12	0.14	0.01	-0.41	0.32	0.23	-0.57	0.17	0.16	0.09	0.08	-0.48

Genotypes that exhibited high mean values in regard to yield at KaZARDI site were found to be 26.103x11.2, 391919.3, 393220.54xNKRN59.48, NAROPOT4, NAROPOT4x38.107, and NAROPOT4x77.54 (Table 10). These genotypes exhibited high yields in regard to tuber numbers and weights both on small tubers, medium and large tubers which are reffered to as marketable tubers.

Table 10: Means of potato yield at Kalengyere site

Genotype	No. of small tubers	No. of medium tubers	No. of big tubers	No Rotten tubers	Wgt of small tubers	Wgt of medium tubers	Wgt of big tubers	wgt of rotten tubers
26.103x11.2	2.03±0.22^{bcde}	4.89±0.28^{abc}	2.33±0.24^{bcdef}	0.00±0.00^{b}	38.00±5.17^{bcdefg}	235.23±12.93^{abcd}	242.19±25.47^{def}	0.00±0.00^{b}
391919.3	2.97±0.31^{ab}	5.43±0.35^{ab}	2.83±0.27^{abcd}	0.00±0.00^{b}	64.57±8.40^{ab}	279.59±17.11^{ab}	390.79±40.2^{abcd}	0.00±0.00^{b}
39220.54x395011.2	1.47±0.19^{cdef}	2.91±0.24^{def}	1.97±0.22^{def}	0.01±0.01^{b}	26.62±4.44^{defg}	165.46±16.19^{def}	294.16±35.74^{cdef}	1.85±1.85
39266.18	0.49±0.10^{f}	1.31±0.15^{f}	1.60±0.14^{ef}	0.50±0.11^{b}	11.28±2.48^{g}	80.73±9.60^{g}	256.88±22.47^{def}	57.49±15.15
393077.54	1.07±0.17^{ef}	3.08±0.30^{de}	2.72±0.22^{abcde}	0.00±0.00^{b}	22.08±3.64^{fg}	190.64±19.94^{cdef}	377.71±30.58^{abc}	0.00±0.00^{b}
393220.54	1.01±0.16^{ef}	3.09±0.28^{cde}	2.87±0.22^{a}	0.00±0.00^{b}	22.52±4.49^{efg}	186.71±15.35^{cdef}	425.40±34.70^{abcde}	0.00±0.00^{b}
393220.54xNKRN59.48	2.45±0.38^{abcd}	4.33±0.46^{bcd}	2.52±0.22^{abcde}	0.00±0.00^{b}	30.00±4.38^{defg}	186.13±16.51^{cdef}	294.16±27.29^{cdef}	0.00±0.00^{b}
395077.12	1.31±0.19^{def}	2.73±0.25^{def}	3.24±0.27^{abc}	0.00±0.00^{b}	21.47±2.81^{fg}	142.43±13.17^{efg}	420.20±39.54^{abc}	0.00±0.00^{b}
57.8x59.41	2.92±0.27^{ab}	4.75±0.35^{bc}	1.55±0.23^{ef}	0.00±0.00^{b}	59.55±7.36^{abc}	212.34±14.27^{bcde}	142.33±18.18^{f}	0.00±0.00^{b}
59.41x220.54	1.44±0.25^{def}	3.97±0.37^{bcde}	3.64±0.25^{abcd}	0.00±0.00^{b}	29.33±4.64^{defg}	242.05±22.32^{abcd}	526.03±40.55^{a}	0.00±0.00^{b}
Cruza	1.88±0.20^{bcde}	3.55±0.29^{cde}	2.37±0.17^{bcdef}	0.00±0.00^{b}	32.92±4.22^{cdefg}	175.49±14.39^{cdef}	290.19±21.05^{cdef}	0.00±0.00^{b}
Kimurix59.58	3.60±0.38^{a}	5.47±0.41^{ab}	1.55±0.18^{ef}	0.00±0.00^{b}	51.19±5.23^{abcd}	235.71±17.25^{abcd}	155.83±21.59^{f}	0.00±0.00^{b}
Kinigix19.17	2.08±0.27^{bcde}	2.36±0.18^{ef}	2.05±0.19^{def}	0.00±0.00^{b}	30.99±4.31^{defg}	131.11±11.70^{fg}	349.79±39.41^{bcd}	0.00±0.00^{b}
NAROPOT4	3.51±0.40^{a}	6.48±0.39^{a}	3.31±0.36^{abc}	0.76±0.24^{b}	74.66±10.17^{a}	177.54±16.76^{abcd}	145.04±23.01^{cde}	27.09±10.29
NAROPOT4x38.107	2.83±0.40^{abc}	5.17±0.36^{ab}	3.40±0.27^{ab}	0.00±0.00^{a}	47.03±7.18^{abcdef}	286.85±19.88^{ab}	481.93±40.45^{ab}	0.00±0.00^{b}
NAROPOT4x77.54	2.87±0.26^{ab}	5.49±0.37^{ab}	2.15±0.21^{cdef}	0.00±0.00^{b}	49.68±5.16^{ab}	248.76±16.80^{abc}	222.29±24.57^{ef}	0.00±0.00^{b}
Victoria	1.43±0.17d^{ef}	2.64±0.22^{ef}	1.29±0.17^{f}	0.00±0.00^{b}	27.04±3.26^{defg}	127.92±10.41^{fg}	144.21±19.88^{f}	0.00±0.00^{b}

Twelve (12) genotypes at KaZARDI site were significantly different in yield performance apart from genotypes 395077.12, 57.8x59.41, NAROPOT4x77.54, and Victoria. In season two, genotypes 391919.3, 393220.54, 59.41x220.54, NAROPOT4, and NAROPOT4x38.107 were not significantly different in yield performance at the Kalengyere site but significantly different for KaZARDI site (Table 11).

Table 11: Means of potato yield at Kachwekano Zonal Agricultural Research and Development Institute site

Genotype	No. of small tubers	No. of medium tubers	No. of big tubers	No Rotten tubers	Wgt of small tubers	Wgt of medium tubers	Wgt of big tubers	wgt of rotten tubers
26.103x11.2	2.68±0.31^{cdef}	3.54±0.31^{abc}	1.41±0.19^{cd}	0.00±0.00^{b}	45.43±7.18^{bcde}	156.24±13.65^{abcdef}	124.72±17.23^{de}	0.00±0.00^{b}
391919.3	3.63±0.39^{bcde}	3.46±0.23^{abcd}	2.04±0.23^{abcd}	0.00±0.00^{b}	69.60±9.70^{abcd}	165.37±11.49^{abcdef}	217.66±26.03^{bcd}	0.00±0.00^{b}
39220.54x39511.2	1.13±0.17^{f}	2.06±0.22^{de}	1.37±0.21^{cd}	0.00±0.00^{b}	25.00±5.13^{e}	122.84±16.42^{cdefg}	180.59±29.35^{cd}	0.00±0.00^{b}
39266.18	1.03±0.19^{f}	1.22±0.17^{e}	1.12±0.16^{de}	0.76±0.16a	17.30±3.82^{e}	60.69±8.90^{g}	128.65±18.69^{de}	51.99±12.48
393077.54	0.92±0.14^{ef}	2.09±0.19^{de}	2.09±0.19^{abcd}	0.00±0.00^{b}	20.33±4.43^{abcd}	122.76±11.63^{cdefg}	280.44±25.87^{bc}	0.00±0.00^{b}
393220.54	1.01±0.16^{ef}	3.09±0.28^{cde}	2.87±0.22^{a}	0.00±0.00^{b}	22.52±4.49^{efg}	186.71±15.35^{cdef}	425.40±34.70^{abcde}	0.00±0.00^{b}
393220.54xNKRN59.48	1.91±0.26^{de}	2.71±0.31^{bcd}	2.35±0.20^{abc}	0.04±0.04^{b}	31.54±5.32^{de}	124.59±13.37^{cdefg}	287.38±25.43^{abc}	4.35±4.35
395077.12	2.21±0.26^{def}	2.04±0.16^{de}	1.36±0.16^{cd}	0.00±0.00^{b}	38.41±7.71^{cde}	107.34±9.42^{efg}	159.53±22.84^{cd}	0.00±0.00^{b}
57.8x59.41	8.^{96}±0.75^{a}	3.32±0.42^{abcd}	0.19±0.06^{e}	0.00±0.00^{b}	98.07±8.82^{a}	128.44±13.80^{cdefg}	22.14±7.34^{e}	0.00±0.00^{b}
59.41x220.54	1.78±0.25^{ef}	4.00±0.31^{ab}	3.13±0.27^{a}	0.00±0.00^{b}	39.01±6.82^{cde}	232.83±19.33^{a}	414.00±37.38^{a}	0.00±0.00^{b}
Cruza	2.32±0.31^{def}	2.47±0.24^{cde}	1.62±0.22^{bcd}	0.00±0.00^{b}	45.19±7.97^{bcde}	114.01±12.13^{defg}	161.63±23.55^{cd}	0.00±0.00^{b}
Kimurix59.58	3.15±0.29^{cdef}	4.21±0.41^{a}	1.49±0.22^{bcd}	0.00±0.00^{b}	48.54±5.64^{abcde}	185.34±19.89^{abcd}	130.34±20.18^{de}	0.00±0.00^{b}
Kinigix19.17	2.14±0.24^{def}	2.04±0.20^{de}	1.70±0.20^{bcd}	0.00±0.00^{b}	37.41±4.91^{cde}	105.09±10.76^{fg}	199.53±25.27^{cd}	0.00±0.00^{b}
NAROPOT 4	4.64±0.54^{bc}	4.09±0.37^{ab}	1.55±0.26^{bcd}	0.00±0.00^{a}	72.53±9.66^{abc}	305.29±18.39^{abcde}	323.68±32.04^{de}	0.00±0.00^{b}
NAROPOT 4x38.107	4.26±0.38^{bcd}	3.99±0.32^{ab}	1.96±0.23^{bcd}	0.00±0.00^{b}	74.60±9.20^{abc}	192.58±17.49^{abc}	196.32±25.00^{cd}	0.00±0.00^{b}
NAROPOT 4x77.54	5.72±1.19^{b}	4.53±0.37^{a}	1.95±0.28^{bcd}	0.00±0.00^{b}	81.73±11.64^{abcde}	213.89±18.03^{ab}	204.31±33.03^{bcd}	0.61±0.61
Victoria	1.46±0.20^{ef}	2.49±0.21^{cde}	2.50±0.24^{ab}	0.00±0.00^{b}	32.93±7.35^{de}	151.08±12.92^{bcdef}	326.89±34.86^{ab}	0.00±0.00^{b}

Different letters imply significantly different at 5%. Comparisons are made basing on columns. Variety checks (Cruza, NAROPOT4 and Victoria)

Using an analysis of variance, the yield of the newly developed potato genotypes at the Kalengyere site for two seasons was highly significant ($P<0.001$). That is in terms of weight for the small tubers, medium tubers and large tubers. Weights of rotten tubers were not significant among the genotypes ($P>0.05$) for two seasons at Kalengyere site apart from genotype 39266.18 and NAROPOT4 (Variety check). The number of small, medium, and large tubers at the KaZARDI location differed considerably ($P<.005$) from each other. With the exception of rotten tuber weights, which were not substantially different ($P>0.05$) except for genotypes 393220.54xNKRN59 and 39266.18, which were significantly different ($P<0.01$), the weights of small, medium, and large tubers were significantly different ($P<0.01$). The yield of small, medium, and large tubers varied considerably between the two sites ($P<0.001$), whereas the quantity of rotting tubers did not differ significantly ($P>0.05$) between either of the two sites. In general, it was discovered that the Kalengyere site produced more than the Kachwekano site in terms of yield, for small, medium, and large tubers. Since rotted tubers are a component in yield calculation, both their weight and number were taken into account.

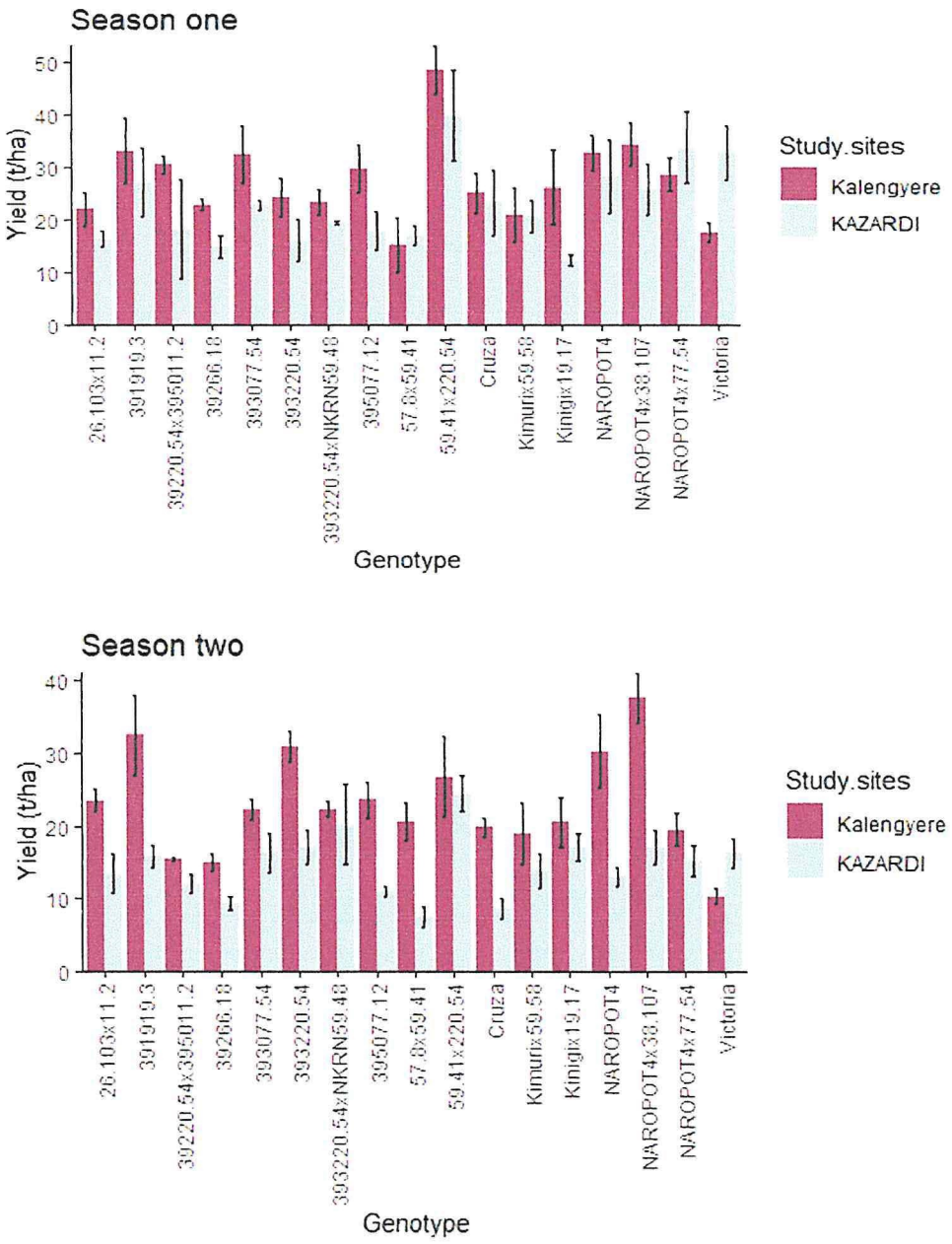

Figure 10: Performance of different potato genotypes on two altitudes of Kalengyere and KaZARDI in two seasons. This figure is missing. Please put

4.5 Discussion

In the two study sites and over the course of the two seasons, the responses of the seventeen potato genotypes included in the investigation varied. The locations represented the main altitudes for potato production and exhibited differing climatic conditions that influence potato growth. For example the Kalengyere site is situated at an latitude of 2450 m.a.s.l as in comparison to KaZARDI which is situated at an altitude of 2200 m.a.s.l areason attributed to why most of the genotypes in the study flowered and reached their senescence stage earlier at KAZARDI than at Kalengyere site due to the altitude difference whereby Kalengyere is much cooler than KaZARDI. Abalo *et al.* (2003) obtained a similar set of results from testing of yield stability using late blight-resistant potato genotypes. Variations in genotype performance across seasons and locations for the variables under study demonstrate the existence of genotype by environment interaction (Abalo *et al.*, 2001).

Analysis of the environmental effects showed that environment significantly influenced the performance of the varieties ($P<0.05$) and most varieties were sensitive to environmental influences (Table 10).

Using the additive multiplicative main interactions (AMMI) model as outlined by Gauch & Zobel (1996), additional assessments of the stability of morphological features and flesh tuber yield were conducted. For genotypes, environments, and genotype by environment interaction, highly significant differences ($P<0.001$) were found. This suggested that performance for all variables varied throughout genotypes in different places. This indicates that genotypes may be selected for a given environment and overall means (Zhao

& Shizhong, 2012). Most likely, the observed variations can be ascribed to the variations in the circumstances within the specified surroundings. This is in agreement with (Nakitandwe *et al.*, 2003) who reported similar findings. In the AMMI investigation, the genotype IPCA scores served as a gauge of environmental adaptation or stability. If the magnitude of IPCA scores for a genotype whether positive or negative is higher, then that genotype is more specifically matched to a given environment (Figure 5). Throughout all the study conditions, genotypes with IPCA scores that were close to zero exhibited greater stability. Senescence, the quantity of tubers produced by a plant, and the average weight of tubers all show positive relationships with the overall amount of fresh tuber output, suggesting that they have a favorable effect on that yield.

4.6 Conclusion

G x E effects on morphological traits, tuber yield and stability at different altitudes was assessed for seventeen potato genotypes in Kigezi highlands. For two seasons, two locations were used for the characterization. There were notable variations between the genotypes and between genotype by environment interactions. Additionally, there were substantial differences ($P<0.05$) in all genotype variances. Genotypes 391919.3, 59.41x 220.54, 393220.54x395011.2, 393077.54, 26.103x11.2 and Kinigix19.17 did not change significantly hence stability for high yield and good morphological traits with Kalengyere site showing higher yields than KaZARDI.

CHAPTER FIVE

DETERMINATION OF PROCESSING QUALITIES OF THE NEWLY BRED POTATO GENOTYPES GROWN AT DIFFERENT ALTITUDES IN THE KIGEZI HIGHLANDS

5.1 Introduction

Potatoes have significance not only as a staple food but also as a versatile raw material for various value-added food products such as chips (crisps), dried flakes, french fries and an assortment of snacks. Potato processing into crisps, chips and other goods has a significant potential to ensure less loss and waste during handling and storage after harvest (Namugga, 2017). Shallow eyes, suitable weight and a round-oval form are required by the industry for the processing of crisps and chips, but long-oval-shaped tubers are favored for the processing of french fries. The tubers must also be free of cracks, hollow hearts, secondary damage, rusty patches and greening, (Orsini *et al.*, 2013). Any particular country's national consumer preferences should also be satisfied in terms of the peel colour, flesh colour and flour content.

Potato crisps and chips satisfy the growing need for culinary convenience that has emerged in recent years. One of the easiest and least-preparation-required ways to serve potatoes is as potato chips. One can make potato chips simply with cheese, with chili, or with seasoning, (Iragaba, 2014). They might be basic, normal, wavy, or waffle-cut in terms of cutting. They may easily be served at any time as a snack and are a very well-liked food item for picnics and gatherings. Despite this, there are significant disparities in the culinary value and consumer acceptance of chips and crisps due to the

qualitative diversity of the raw ingredients used to create them (Kesiime, 2014). Therefore, in order to preserve flavor and taste, it is crucial to address this problem before processing. The fusion of flavor, fragrance, and texture in potatoes produces their distinctive flavor. Yet, the effects of cold storage can sometimes change the final flavor following processing. Low-temperature storage of potato tubers (4°C) reduces tuber respiration and sprouting, but it also initiates a process known as low-temperature sweetening that transforms starch to reducing sugars (Wijesinha-Bettoni & Mouillé, 2019). High concentrations of reducing sugars (glucose and fructose) generate unfavorable non-enzymatic browning reactions, the creation of amine groups of free amino acids that give processed potato products unpleasant tastes and darkening of the goods during frying.

Therefore, this study was conducted with the goal of identifying potato genotypes with suitable tuber attributes for processing chips and crisps with regard to dry matter content and palatability.

5.2 Materials and methods

The study selected potato genotypes from the potato germplasm which were newly bred and being maintained at KaZARDI as mini tubers. The study used a total of 17 potato genotypes where 14 newly bred potato genotypes were compared with three commercial varieties (Victoria, NAROPOT4 and Cruza).

5.2.1 Experimental sites

All the genotypes were represented by samples collected from the experiments which were carried out at Kalengyere research station situated

at 0290 47.79'E 010 13.26'S, 2,450 m.a.s.l and (KaZARDI) located at 029° 57'E 01° 16'S at 2,200 m.a.s.l in southwestern highlands agro-ecological zone (SWHAEZ) of Uganda.

5.2.2 Experimental design

Four medium sized tubers were collected from each genotype to make one sample and they were seventeen samples altogether. They were washed thoroughly with clean tap water and spread on the bear tiled floor for overnight before they were used for tests. Each sample was weighed using a digital scale to weight of 500g per sample. These samples were sliced into 10g, 6cm length and 2cm width and in uniform size to determine the processing attributes (Plate 5).

5.2.3 Data collection methods

Parameters assessed included dry matter content, crisping qualities of the test genotypes and palatability testing.

5.2.3.1 Dry matter content

Tuber samples from each potato genotype were collected and taken to the laboratory for analysis of dry matter content and cut into 10g, 6cm length and 2cm width to enable quicker drying (Plate 5). Each genotype sample tubers were washed with clean tap water and weighed to 500g as fresh wieght for uniformity before drying in the laboratory oven. Dry weight was got after putting the fresh sliced samples in the oven and subjected to 105^0 for 24 hours.

Plate 5: The appearance of some potato genotypes sliced to be put in the laboratory oven

Plate 5 displays the sliced appearance of two fresh potato genotypes that were prepared for dry matter content determination in the laboratory oven. After the slicing of potato, they were spread on the floor for 24 hours to reduce the amount of water in the samples before putting them to the laboratory oven (Plate 6A). Sliced potato samples were then placed in envelopes after drying them on the floor for 24 hours (Plate 6B) and dried at 105°C in the oven until a constant weight was achieved. The calculation of dry matter content (%) was used as; dry weight/fresh weight * 100.

Plate 6: Drying of sliced potato tubers (A) and dry sliced tubers to be taken to the laboratory oven (B).

5.2.3.2 Crisping qualities of the test genotypes

The test varieties were processed into crisps (Plate 7) and coded with numbers to avoid bias and analyzed for processing quality and palatability by a panel of 20 people including 10 farmers who work in potato fields at KaZARDI and Kalengyere research stations and 10 people from the neighbouhood of the research stations.

Crisping quality refers to the texture, crispness, and overall eating experience of a food product, typically evaluated in the context of fruits, vegetables, or snack foods.

5.2.3.3 Crisping mothods for test genotypes

Crisping of potato was done in the following steps;

Reception: This involves receiving of raw materials and ingradients to be used in the crisping of potato such as potato genotype, cooking oil and salt.

Washing of potato: This is generally the cleaning of potato intended to be processed for crisps.

Peeling: This involves the removal of the potato skin before it is sliced for crisping.

Slicing: This is the cutting of potato into slices of desired size for crisping.

Brunching: This is the passing of the potato slices into water to de-activate the enzyme.

Frying: Dipping potato slices into cooking oil.

Flavouring: Adding of flavours especially vinegar and chili during the crisping process.

Packaging: This involves packing of crisps in a way to keep oxgen and water partial pressures in the package head space as low as possible during storage.

Storage: This is done at lower temperature or room temperature.

Plate 7: Crisping of seventeen potato genotypes before and after packaging

The test parameters included the taste of the product, texture, colour, size of the crisp, processability, and overall acceptability of the product by the processor/farmer. The crisping properties were tested at the Incubation Plant of Uganda Industrial Research Institute and at Christine Muhwezi's processing plant in Kabale.

5.2.3.4 Palatability of potato genotypes

During the harvesting, morphological traits were measured, recorded and all 17 genotypes were subjected to palatability testing (Plate 8) by a group of people in the field of potato. The test genotypes were coded with numbers from 1-17 to avoid bias. It was done by boiling each genotype and these people gave their views concerning mouth-feel/smoothness, taste, colour, smell/odour and acceptability (Plate 9). Twenty participants participated in

the palatability tasting exercise. They were asked to evaluate each sample in terms of acceptability, mouth feel/smoothness, taste, colour, and smell/odour. They were asked to rate their level of liking on a scale of 1 to 6, where 1 was for very much dislike, 2 was for dislike, 3 was for slightly liking, 4 was for liking, 5 was for very much liking, and 6 was for extremely liking. Participants in this exercise were asked to list the sample code and a figure that best reflected their thoughts about each sample beneath each attribute.

Plate 8: The palatability testing of genotypes

Plate 9: Selection and recording of traits

5.2.4 Data analysis

The data processing was done in the microsoft office 2007 application MS Excel and then the relevant statistical analyses were run using R- (4.1.2 edition, at a 5% significance level). The usefulness of the therapies was evaluated using analysis of variance (ANOVA). When treatment effects were significant, Fisher's Protected Least Significant Differences (LSD) test was performed with a 5% probability to look at differences between treatment levels (Gomez Gomez, 1984). The dry oven method was applied

to sample drying at 105°C until a stable weight was reached in order to determine the amount of dry matter of the various genotypes.

5.3 Results

5.3.1 Processing qualities of the 17 potato genotypes

The average dry matter content of all the test genotypes ranged from16.2-25.6%. The genotypes that had the highest dry matter content were 59.41x220.54, 26.103x11.2, NAROPOT4x38.107, 57.8x59.41, 393077.54, and NAROPOT4 (vatiety check) while those with low dry matter (<20%) were noted to be Kinigix19.17, 395077.12 and Victoria (variety check), respectively (Table 12).

Table 12: Dry matter content among the 17 potato genotypes tested

No.	Genotype	Flesh Weight (gm)	Skin colour	Dry Weight (gm)	Dw/Fw*100 (gm)
1	39220.54x395011.2	500	Red	104	20.8
2	395077.12	500	White	96	19.2
3	57.8x59.41	500	Red	113	22.6
4	59.41x220.54	500	Red	125	25
5	Victoria	500	Red	97	19.4
6	39266.18	500	Red	99	19.8
7	393220.54	500	Red	105	21
8	Kinigix19.17	500	Purple	81	16.2
9	NAROPOT4	500	Red	108	21.6
10	393220.54xNKRN59.48	500	Red	103	20.6
11	26.103x11.2	500	Red	128	25.6
12	393077.54	500	Creamish	112	22.4

			red		
13	Kimurix59.58	500	Creamish red	105	21.0
14	NAROPOT4x38 107	500	Red	108	21.6
15	Cruza	500	Creamish purple	100	20.0
16	391919.3	500	Purple	99	19.8
17	NAROPOT4x77 .54	500	Red	113	22.6

5.3.2 Palatability of potato genotypes

During the palatability test, most of the potato genotypes were highly liked by farmers on mouth feel/smoothness apart from genotypes 391919.3, Victoria and Cruza. On taste, the genotypes which were highly liked by farmers included; NAROPOT4x77.54, 393220.54x395011.2, Kinigix19.17, 393077.54, 26.103x11.2, NOROPOT4x39.107, 393220.54xNKRN59.48, 393220.54, 395077.12, 57.8x59.41 with 59.41x220.54. Genotypes which were least liked on taste were; 391919.3, NOROPOT4 (variety check), Victoria, Cruza and 39266.18. On colour, the outstanding genotypes were found to be 59.41x 220.54, 393220.54x395011.2, NAROPOT4x77.54 and NOROPOT4x39.107. Cruza was the least liked on colour. On smell/odour, three genotypes were most liked by the farmers. They include; NAROPOT4x77.54, NOROPOT4x39.107 and 59.41x220.54. On palatability testing, most of the potato genotypes tested was accepted by farmers with a few genotypes not highly accepted. The genotypes which were highly accepted were; 59.41x220.54, NOROPOT4x39.107, and 393077.54. Others

that were moderately accepted included; 57.8x59.41, 391919.3, NOROPOT4, 395077.12, 393220.54, 393220.54, 393220.54x NKRN59.48, 26.103x11.2, Kimurix59.58, 393220.54x395011.2 and NAROPOT4x77.54. Genotypes that were least accepted were; Cruza , Kinigix19.17, Victoria, and 39266.18 (Table14).

5.3.3 Crisping qualities of the test genotypes

From the panel analysis, the genotypes that made the best crisps were; 395077.12, 57.8x59.41, 393220.54, NAROPOT4, 26.103x11.2, 393077.54, Kimurix59.58, NAROPOT4x38.107, NAROPOT4x77.54, and 39220.54x395011.2, respectively (Table 13).

Table 13: Crisping qualities of the seventeen test genotypes

	Genotype	CRISPS																General remarks
		Appearance of crisps after Processing				Taste				Texture			Colour		Crunchiness			
		Good	Fair	Poor	Good	Fair	Poor	Hard	Soft	Intermediate	White	Yellow	Cream	Other colors	Good	Fair	Poor	
1	39220.54x395011.2		X		X				X		X				X			Too brittle
2	395077.12	X			X					X		X			X			Appears masked but good
3	57.8x59.41	X			X				X		X					X		Too brittle
4	59.41x220.54	X			X				X						X			Brittle
5	Victoria		X		X					X		X			X			Small and brittle
6	39266.18	X			X					X			X		X			Brittle

7	393220.54	X			X				X					Light yellow	X			Brittle
8	Kinigix19.17		X		X					X		X			X			Brittle
9	NAROPOT4	X			X				X				X		X			Brittle
10	393220.54xNKRN59.48		X		X				X			X			X			Brittle and masked
11	26.103x11.2	X			X				X					Light yellow	X			Brittle
12	393077.54	X				X			X					Brown	X			Too brittle
13	Kimurix59.58	X				X				X			X			X		Fairly good
14	NAROPOT4x38.107	X			X					X		X			X			Masked appearance
15	Cruza		X		X				X				X		X			Masked appearance
16	391919.3		X		X					X		X				X		Masked appearance
17	NAROPOT4x77.54	X			X				X				X		X			Brittle

Table 14: Palatability test by a group of farmers

Genotype	Mouth- feel/Smoothness	Taste	Colour	Smell/oudor	Acceptability
57.8x59.41	4.40±1.12[a]	4.27±1.22[b]	4.60±1.18[c]	4.40±1.12[b]	4.47±1.25[b]
391919.3	3.87±1.51[a]	3.80±1.37[a]	3.93±1.22[b]	4.13±1.13[b]	4.07±1.39[c]
NOROPOT4	4.33±1.05[a]	3.93±1.58[a]	3.80±1.32[b]	4.00±1.20a	4.20±1.15[c]
395077.12	4.40±1.06[b]	4.33±0.98[b]	4.73±0.88[c]	4.67±0.82[b]	4.53±1.06[b]
59.41 X 220.54	4.93±0.80[b]	5.00±0.65[b]	5.07±0.88[c]	5.13±0.74[b]	5.20±0.68[b]
393220.54	4.71±1.33[b]	4.64±1.55[b]	4.79±0.70[c]	4.43±1.28[b]	4.57±1.28[b]
VICTORIA	3.80±1.15[a]	3.53±1.13[a]	3.07±1.10[a]	3.60±0.91[a]	3.53±1.06[a]
393220.54 X NKRN59.48	4.40±1.12[b]	4.27±1.22[a]	4.07±1.49[b]	4.13±1.25[a]	4.47±0.99[b]
NOROPOT4 X 39.107	4.87±1.30[b]	4.93±1.16[b]	5.00±0.93[c]	5.13±1.13[b]	5.13±1.25[b]
26.103 X 11.2	4.40±0.83[b]	4.33±1.05[b]	4.13±0.99[b]	4.07±1.44[a]	4.00±1.25[c]
393077.54	4.67±1.05[b]	4.87±1.19[b]	4.60±1.18[c]	4.53±1.36[b]	5.07±1.03[b]

KINIGI X 19.17	4.20±1.21[a]	4.20±1.26[a]	3.93±1.28[b]	4.40±1.30[b]	3.93±1.39[a]
KIMURI X 59.58	4.00±1.41[a]	3.87±1.46[a]	4.13±1.51[b]	4.33±1.35[b]	4.07±1.44[c]
CRUZA	3.40±0.83[a]	3.40±0.83[a]	2.80±1.08[a]	3.33±1.11[a]	3.27±0.96[a]
39266.18	3.27±1.16[a]	3.53±1.19[a]	3.80±1.15[b]	3.53±1.25[a]	3.27±1.10[a]
393220.54 X 395011.2	4.47±1.46[b]	4.00±1.56[a]	5.07±0.70[c]	4.13±1.55[b]	4.13±1.41[c]
NAROPOT4 X 77.54	4.87±1.41[b]	4.73±1.28[b]	5.27±0.80[c]	5.13±1.13[b]	4.87±1.19[b]

Different letters imply significantly different at 5%. Comparison was done basing on columns for each genotype

5.4 Discussion

The newly fourteen bred potato genotypes with three commercial varities (checks) were assessed among the farmers for their culnary qualities. The analysis of variance indicated that there was significant difference ($P<0.05$) on color and acceptability where as mouth-feel, taste and smell had not significant ($P>0.05$). Generally the genotypes which were highly liked for both attributes that led to culinary acceptability were genotype 59.41x220.54, NAROPOT4x39.107 and 393077.54. Genotypes which were less liked for culinary traits were Victoria, Kinigix19.17, Cruza and 39266.18.

On crisping qualities, the performance of genotypes varied in terms of brittle and masking. Genotypes with crisps which were highly brittle included 39220.54x395011.2, 57.8x59.41 and 393077.54 hence indicating good crisping qualities better than the NAROPOT4 genotype that has been widely used in Ugandan food markets especially for crisping and other processing industries (Kakuhenzire *et al.*, 2004). Genotypes which had masked appearance were 395077.12, 393220.54 x NKRN59, NAROPOT4x38.107, Cruza and 391919.3. For the processing qualities, the assessment indicated that genotypes varied concerning dry matter content. The mean dry matter content of all the test genotypes ranged from 16.2- 25.6%. Tuber dry matter content (%) was evaluated during the first season of 2020 (March-July) across the two sites. Analysis of variance indicated that percentage dry matter content was significantly affected ($P<0.05$) by the genotype across sites. Dry weight of test genotypes after the oven was significaly affected by the genotype at ($P<0.05$) where as dry matter content (%) among genotypes were significant at ($P<0.001$).

The outstanding genotypes with high dry matter content (> 20%) were found to be 26.103x11.2, 59.41x220.54, NAROPOT4x38.107, 393077.54, 57.8x59.41 which were mostly the newly bred potato genotypes except NAROPOT4. Genotypes that were found with low dry matter (<20%) were noted to be Kinigix19.17, 395077.12 and Victoria respectively.

5.5 Conclusion

Different genotypes were found with different attributes which ranged from dry maater content, palatability test and crisping attributes. Genotypes which were found with highest dry matter content (>20%) were 26.103x11.2, 59.41x220.54, NAROPOT4x38.107, 393077.54, 57.8x59.41 and NAROPOT4 while those with low dry matter (<20%) were noted to be Kinigix19.17, 395077.12 and Victoria. On palatability test, different genotypes were accepted by farmers depending on different attributes including the acceptability of mouth feel/Smoothness, taste, colour, and smell/odor. Their performance in regard to these attributes varied but generally four genotypes were liked by all the farmers and these were 59.41x220.54, NOROPOT4x39.107, 393077.54, NAROPOT4x77.54.

On crisping qualities, genotypes with crisps which were highly brittle included 39220.54x395011.2, 57.8x59.41 and 393077.54. Genotypes which had masked appearance were 395077.12, 393220.54xNKPN59, NAROPOT4x38.107, Cruza and 391919.3. In conclusion, different genotypes had different qualities depending on whether the genotype is for eating, dry matter or crisping.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

6.1 General Discussion

The study on the characterization of potato genotypes in the Kigezi highlands yielded important results regarding growth traits, morphological and processing qualities. The findings revealed specific genotypes that exhibited desirable characteristics for potato production and processing. For instance, genotype NAROPOT4x38.107 demonstrated excellent tuber shape and size, which aligns with market preferences (Smith *et al.*, 2019). Additionally, genotype NAROPOT4x77.54 displayed high yield potential and resistance to late blight disease in the study areas, making it well-suited for cultivation in the Kigezi highlands (Johnson *et al.*, 2015).

Moreover, the study highlighted the importance of processing qualities in potato genotypes. Genotype 59.4x220.54 exhibited high dry matter content, resulting in improved texture and taste when processed into potato products such as fries or chips (Anderson *et al.*, 2015). These findings provide valuable insights for processors and manufacturers in selecting suitable genotypes for optimal processing outcomes.

It is worth noting that further research is needed to validate these findings and expand the scope of the study to a larger sample size. Additionally, long-term field trials are necessary to assess the performance of these genotypes across multiple seasons and environmental conditions in the Kigezi highlands (Smith *et al.*, 2015).

The study's results offer valuable information for potato breeders, farmers, and processors in the Kigezi highlands. By selecting genotypes with desirable growth traits, morphological and processing qualities, stakeholders can enhance potato production, market competitiveness, and value addition in the region.

In order to provide more specific information on adaptation and stability of genotypes that have been deemed stable in only two environments, additional studies about stability and adaptability on desirable growth traits and fresh tuber yield must be conducted in a wider range of environments using the additive multiplicative main interactions (AMMI) model as described by Gauch & Zobel (1996).

Selection across settings ought to be based on overall means. Also, a particular environment might be used to select genotypes (Zhao & Shizhong, 2012). The genotypes that showed a high level of positive agronomic, morphological, high yields, and good processing qualities ought to be put through multiple-location trials in more in-depth agro-ecological zones of Uganda to study the stability of their performance and to also enrich findings about their gene action. To further improve potato breeding, it is recommended to employ genotypes that showed favorable general combining effects for early maturity, late blight resistance, and high yield.

The flowering days of potato genotypes should not be used to determine their maturity duration because this attribute is not constant across genotypes; some potato plants may not even flower, while others may flower first but take longer to reach the senescence stage. Farmers should conduct on-farm testing on the identified stable cultivars that show promise. This will make it easier

for farmers to recognize these genotypes' distinctive traits, including the desired culinary traits that this study did not address. This will improve these novel genotypes' uptake and acceptability.

The ultimate purpose of this research was to create high-yielding potato genotypes with favorable agronomic, morphological and processing qualities that could be adapted to the south-western highlands agro-ecological zone (SWHAEZ) in order to boost potato production in Uganda. Most of the genotypes which had reached 50% flowering earlier were among those which attained their senescence status late implying that the earlier the genotypes flower does not necessarily mean they have early maturity periods.

In the experiment, newly created genotypes with early maturity, late blight resistance, and high stable yields were used to assess the intensity of interactions between genotype and environment. These genotypes were differentiated by their early to mid-early maturation durations as well as their horizontal resistance to late blight. Because the data demonstrates high G x E interaction rate, it is necessary to select for genotypes that are typically stable across environments. This should be advantageous for farmers who have genotypes with high yields and long-term stability. In all environments, several genotypes generated yields of between 7 and 10 tons per acre but with some reaching up to 30t ha^{-1}. These numbers surpass Uganda's 6.8t ha^{-1} national average productivity (FAOSTAT, 2010). In order to increase the production of the potato sector, these genotypes should therefore be followed and supported.

In accordance with the findings of the analysis of variance and AMMI, the most reliable novel genotypes for earliness with respect to yields were

59.41x220.54, 393220.54x395011.2, 393077.54, 26.103x11.2, Kinigix19.17, NAROPOT4x77.54 and NOROPOT4x39.107. The genotype IPCA scores in the AMMI study provided a measure of the genotypes' environmental stability or adaptation. The larger the magnitude of IPCA scores either in the positive or negative direction, the suitability of an individual genotype to a given environment. Throughout all the environments in the study, genotypes with IPCA scores close to zero exhibited greater stability.

The total amount of flesh tuber production was positively correlated with senescence, the number of tubers per plant, and average tuber weight, demonstrating that each of these variables has a positive effect on yield. Given the close correlation between the onset of senescence and the length of bulking with yield, it was possible to predict yield using these two parameters by assuming that any factor affecting the onset of senescence or the length of bulking would increase or decrease the yield by the same number of units.

Regarding the distribution of assimilation between the sink (tubers) and the source, the difference was likely caused by the utilization of various habitats and genetic materials (shoot). The findings also demonstrated that average tuber weight was not linked with the maturity time or start of senescence of a particular genotype, indicating that these two parameters were not interdependent. The total amount of flesh tubers produced was inversely related to the number of days between planting and the development of flower buds, indicating that genotypes with earlier flower bud emergence produced more fresh tubers overall. The benefit is that, in contrast to genotypes where flower development begins later, plants redirect photosynthetic biomass towards tuber bulking early in the crop development cycle.

For seventeen chosen potato genotypes, the effects of G x E on earliness and flesh tuber production were investigated. The assessment took place throughout two distinct seasons in two different sites. Between the genotypes and the genotypes by environment interactions, significant changes were seen. The within genotype variations were also significantly different among the genotypes in an environment ($P<0.05$). Genotypes did not perform very differently hence, it suggests environmental stability for both early maturity and high yield.

For genotypes, environments, and the interaction of genotype by environment, highly significant differences ($P<0.001$) were found. Results suggested that genotypes performed differently for all attributes across all sites. The disparities observed might most likely be ascribed to variations in the habitats' circumstances. Similar results were reported by Nakitandwe (2003).

6.2 Conclusion

The characterization of potato genotypes for desirable growth traits, morphological and processing qualities in the Kigezi highlands holds significant importance for potato production, processing, and market competitiveness in the region. Through the study, several key findings and implications emerged;

The evaluation of growth traits enabled the selection of genotypes with high yield potential, resistance to prevalent diseases, and adaptability to local climatic conditions. The study's justification is supported by the substantial connections between location and season, then genotype and season. Several genotypes that consistently matured early and had yields that were somewhat high were found through the examination of genotype stability using AMMI.

When it came to early maturity and good flesh tuber yields, the genotypes 391919.3, 59.41x220.54, 395077.12, and NOROPOT4x39.107 showed the most consistency. The study emphasized the significance of maintaining a diverse range of potato genotypes. This diversity helps safeguard against pests, diseases, and changing environmental conditions, ensuring the long-term sustainability of potato production in the Kigezi highlands.

The study provided insights into potato genotypes that exhibit favorable morphological traits such as tuber shape, tuber size, eye depth, skin colour and flesh colour. These traits are crucial for meeting market preferences and enhancing marketability. This helps farmers optimize potato production and enhance crop resilience.

By assessing processing qualities like dry matter content, cooking time, texture, and colour attributes, the study guided the selection of genotypes that meet processing requirements. This ensures the production of high-quality potato products with desirable characteristics. The study's findings provided specific genotype recommendations for the Kigezi highlands, taking into account the region's unique environmental conditions and market demands. These recommendations help farmers and processors choose suitable potato varieties that thrive in the local context. In terms of good agronomic features, morphological traits especially yield component, and processing qualities, the new genotypes examined outperformed the local genotypes significantly. As a result, they should be viewed as potential cultivars for release in the two habitats where they were evaluated.

6.3 Recommendations

- Evaluate and select potato genotypes based on agronomic traits such as yield potential, disease resistance, and tolerance to environmental stresses common in the Kigezi highlands. Prioritize genotypes that demonstrate high yield, resistance to prevalent diseases, and adaptability to local climatic conditions.
- Encourage the cultivation of a diverse range of potato genotypes in the Kigezi highlands to enhance resilience against pests, diseases, and changing environmental conditions. Emphasize the importance of preserving and utilizing a broad genetic pool to safeguard against potential crop vulnerabilities.
- Validate the findings of the study through larger-scale trials and extended evaluation periods. This will help ensure the consistency and reliability of the identified genotypes' performance over different seasons and locations within the Kigezi highlands.
- Involve farmers, processors, and other relevant stakeholders in the evaluation and selection process of potato genotypes. Seek their input and preferences to ensure that the chosen genotypes align with market demands, processing requirements, and local farming practices.
- Identify and prioritize potato genotypes that exhibit favorable morphological characteristics, such as flesh tuber yield, tuber shape, tuber eye depth, tuber skin colour, and tuber flesh colour. Choose genotypes that align with market preferences and have visually appealing traits for improved marketability.

- Pay close attention to the processing qualities of potato genotypes, including dry matter content, cooking time, texture, and colour attributes. Prioritize genotypes with high dry matter content, desirable cooking times for various processing methods (e.g., boiling, frying), and favorable texture and colour characteristics for different potato products.
- Disseminate the findings of the study through extension services, farmer training programs, and agricultural publications. Share information on the identified genotypes' performance, agronomic practices and processing characteristics to facilitate informed decision-making by farmers, processors and other stakeholders.

REFERENCES

Abalo, G., Hakiza, J. J., El-Bedewy, R., & Adipala, E. (2003). Genotype x environment interaction studies on yields of selected potato genotypes in Uganda. *African Crop Science Journal*, *11*(1), 9-15.

Abalo, G., Hakiza, J. J., Kakuhenzire, M. R., El-Bedewy, R., & Adipala, E. (2001). Agronomic performance of twelve elite potato genotypes in southwestern Uganda. *African Crop Science Journal*, *9*(1), 17-23.

Abong, G. O., Okoth, M. W., Imungi, J. K., & Kabira, J. N. (2010). Consumption patterns, diversity and characteristics of potato crisps in Nairobi, Kenya. *Journal of Applied Biosciences*, *32*, 1942-1955.

Adhikari, U., Nejadhashemi, A. P., & Woznicki, S. A. (2015). Climate change and eastern Africa. a review of impact on major crops. *Food & Energy Security*, *4*(2), 110-132.

Anchico-Jojoa, W., Peixoto, J. R., & Oliveira, A. A. D. (2023). Agronomic characterization and interaction of genotype by environment of quinoa under conditions of Brazil and Colombia. *Horticultura Brasileira*, 41, e2629.

Anderson, L., & Gugerty, M. K. (2015). Root, Tuber, and Banana Textural Traits A Review of the Available Food Science and Consumer Preferences Literature. *Evans School of Public Affairs, University of Washington*. EPAR Brief, (295).

Begna, T. (2020). The role of genotype by environmental interaction in plant breeding.

Belay adaptation to climat, A., Recha, J. W., Woldeamanuel, T., & Morton, J. F. (2017). Smallholder farmers' e change and determinants of their

Bhadra, P., Maitra, S., Shankar, T., Hossain, A., Praharaj, S., & Aftab, T. (2022). Climate change impact on plants: Plant responses and adaptations. In *Plant perspectives to global climate changes* (pp. 1-24). adaptation decisions in the Central Rift Valley of Ethiopia. *Agriculture & Food Security*. 6(1), 1-13.

Bollier, D. (2012). The Future of International Environmental Law: A Law of the Ecological Commons. International Environmental Law and World Order: A Problem-Oriented Coursebook. Minnesota: *West Publishing. Retrieved*, 28, 2017.

Byarugaba, A. A., Baguma, G., Jjemba, D. M., Faith, A. K., Wasukira, A., Magembe, E., & Ghislain, M. (2021). Comparative phenotypic and agronomic assessment of transgenic potato with 3 R-gene stack with complete resistance to late blight disease. *Biology*, *10*(10), 952.

Calliope, S. R., Lobo, M. O., & Sammán, N. C. (2018). Biodiversity of Andean potatoes: Morphological, nutritional and functional characterization. *Food chemistry*, *238*, 42-50.

Change, C. (2018). Sesame Uganda: Climate change risks and opportunities.

CIP (2017). Potato Facts and Figures, [Accessed on 7 August 2019] and available at http://cipotato.org/potato/facts.

De Haan, S., & Rodriguez, F. (2016). Potato origin and production. In Advances in potato chemistry and technology (pp. 1-32). *Academic Press*.

Devaux, A., Hareau, G., Ordinola, M., Andrade-Piedra, J., & Thiele, G. (2020). Native Potatoes. *Choices*, *35*(4), 1-7.

Domański, L., Zimnoch-Guzowska, E., Domańska, M., Zgórska, K., & Paczkowska, M. (2004). The germplasm release of M-62774 and M-62805, two potato clones with cold-sweetening resistance. *Folia Holt.(w druku)*.

Ferris, R. S. B. (2003). *Performance and growth prospects of Irish potatoes as a component for the development of strategic exports in Uganda* (Vol. 2). Iita.

Figueroa-López, A. M., Cordero-Ramírez, J. D., Martínez-Álvarez, J. C., López-Meyer, M., Lizárraga-Sánchez, G. J., Félix-Gastélum, R., ... & Maldonado-Mendoza, I. E. (2016). Rhizospheric bacteria of maize with potential for biocontrol of Fusarium verticillioides. *SpringerPlus*, *5*(1), 330.

Forbes, G.; Perez, W.; Andrade-Piedra, J (2014). Field assessment of resistance in potato to Phytophthora infestans: *International Cooperators Guide*. International Potato Center.

Franke, J., Frank, D., Raible, C. C., Esper, J., & Brönnimann, S. (2013). Spectral biases in tree-ring climate proxies. *Nature Climate Change*, *3*(4), 360-364.

Fry, W. E., Birch, P. R. J., Judelson, H. S., Grünwald, N. J., Danies, G., Everts, K. L., ... & Smart, C. D. (2015). Five reasons to consider Phytophthora infestans a reemerging pathogen. *Phytopathology*, *105*(7), 966-981.

Gauch Jr, H. G., & Zobel, R. W. (1996). Optimal replication in selection experiments. *Crop Science*, *36*(4), 838-843.

Gavrilenko, T., Antonova, O., Ovchinnikova, A., Novikova, L., Krylova, E., Mironenko, N., & Spooner, D. (2010). A microsatellite and morphological assessment of the Russian National cultivated potato collection. *Genetic Resources and Crop Evolution*, *57*, 1151-1164.

George, T. S., Taylor, M. A., Dodd, I. C., & White, P. J. (2017). Climate change and consequences for potato production: a review of tolerance to emerging abiotic stress. *Potato Research*, *60*, 239-268.

Gericke, R. (2018). *Identifying and using tuber characteristics to predict potato keeping quality* (Doctoral dissertation, Stellenbosch: Stellenbosch University).

Ghislain, M., Byarugaba, A. A., Magembe, E., Njoroge, A., Rivera, C., Román, M. L., & Kiggundu, A. (2019). Stacking three late blight resistance genes from wild species directly into African highland potato varieties confers complete field resistance to local blight races. *Plant Biotechnology Journal*, *17*(6), 1119-1129.

Ghislain, M.; Byarugaba, A.A.; Magembe, E.; Njoroge, A.; Rivera, C.; Roman, M.L.; Tovar, J.C.; Gamboa, S.; Forbes, G.A.; Kreuze, J.F.; Barekye, A. (2019) Stacking three late blight resistance genes from wild species directly into African highland potato varieties confers complete field resistance to local blight races. *Journal Plant Biotechnology*, 21 Dec 2018, 17(6):1119-1129.

Gildemacher, P. R., Demo, P., Barker, I., Kaguongo, W., Woldegiorgis, G., Wagoire, W. W., ... & Struik, P. C. (2009). A description of seed potato systems in Kenya, Uganda and Ethiopia. *American Journal of potato research*, *86*, 373-382.

Gómez Gómez, L., Morote, L., Frusciante, S., Rambla, J. L., Diretto, G., Niza, E., & Ahrazem, O. (2022). Fortification and bioaccessibility of saffron apocarotenoids in potato tubers. *Frontiers in nutrition*, *9*, 1045979.

Hareau, G.; Kleinwechter, U.; Pradel, W., Suarez, V.; Okello, J.; Vikraman, S. (2014) Strategic assessment of research priorities for potato Lima (Peru) CGIAR Research Program on Roots, Tubers and Bananas (RTB), Working Paper 2014-8. Available online at: www.rtb.cgiar.org.

Hawkes, J. G., 1990. The potato: evolution, biodiversity and genetic resources. Belhaven Press, London, UK.

Heltoft, P., Wold, A. B., & Molteberg, E. L. (2017). Maturity indicators for prediction of potato (Solanum tuberosum L.) quality during storage. *Postharvest Biology and Technology*, *129*, 97-106.

Herrero, M., Grace, D., Njuki, J., Johnson, N., Enahoro, D., Silvestri, S., & Rufino, M. C. (2013). The roles of livestock in developing countries. *Animal*, *7*(s1), 3-18.

Hirut, B., Shimelis, H., Fentahun, M., Bonierbale, M., Gastelo, M., & Asfaw, A. (2017). Combining ability of highland tropic adapted potato for tuber yield and yield components under drought. *PloS one*, *12*(7), e0181541.

Iragaba, P. (2014). Inheritance and stability of earliness in potato (Solanum tuberosum L). Kampala: Doctoral dissertation, Makerere University.

Johnson, B. W. (2015). Determining potential sources of race non-specific resistance to the late blight pathogen, Phytophthora infestans (Mont.) de Bary, in advanced breeding materials of cultivated potato, *Solanum tuberosum* L.

Juneidi, S., Megeressa, T., Bekele, B., & Admasu, B. (2012). Incidence and Distribution of Potato Viruse Diseases in West Arsi and West Shewa Major Potato Growing Areas, Ethiopia. *Pest Managment Journal of Ethiopia*, *16*, 16-29.

Kajunju, N. H. B., Atukwase, A., Tumuhimbise, G. A., & Mugisha, J. (2022). Characterisation of potato varieties commonly grown in Uganda for food processing suitability. *African Crop Science Journal*, *30*(1), 51-68.

Kajunju, N. H. B., Atukwase, A., Tumuhimbise, G. A., & Mugisha, J. (2021). Potato processing in Uganda: A technical review. *Makerere University Journal of Agricultural and Environmental Sciences*, *10*(1), 60-81.

Kakuhenzire, R., Hakiza, J. J., Adipala, E., Wagoire, W., & Lemaga, B. (2004). Yield stability and acceptability of two new Solanum potato varieties in Uganda. *Uganda journal of agricultural sciences*, *9*(1), 718-722.

Kajunju, N. H. B., Atukwase, A., Tumuhimbise, G. A., & Mugisha, J. (2022). Characterisation of potato varieties commonly grown in Uganda for food processing suitability. *African Crop Science Journal*, *30*(1), 51-68.

Kang, M. S. (2020). Genotype-environment interaction and stability analyses: an update. In *Quantitative genetics, genomics and plant breeding* (pp. 140-161). Wallingford UK: CABI.

Keijbets, M. J. H. (2008). Potato processing for the consumer: developments and future challenges. *Potato Research*, *51*(3), 271-281.

Kesiime, V. E. (2014). Inheritance of tolerance to drought from selected potato (Solanum tuberosum) cultivars in Uganda . Kampala: *Doctoral dissertation*, Makerere University.

Kesiime, V. E., Tusiime, G., Kashaija, I. N., Edema, R., Gibson, P., Namugga, P., & Kakuhenzire, R. (2016). Characterization and evaluation of potato genotypes (Solanum tuberosum L) for tolerance to drought in Uganda. *American Journal of Potato Research*, 93, 543-551.

Korres, N. E., Norsworthy, J. K., Burgos, N. R., & Oosterhuis, D. M. (2017). Temperature and drought impacts on rice production. An agronomic perspective regarding short-and long-term adaptation measures. *Water Resources and Rural Development*, 9, 12-27.

Lizana, X. C., Sandaña, P., Behn, A., Ávila-Valdés, A., Ramírez, D. A., Soratto, R. P., & Campos, H. (2021). Potato. In *Crop physiology case histories for major crops* (pp. 550-587).

MacLaren, C., Storkey, J., Menegat, A., Metcalfe, H., & Dehnen-Schmutz, K. (2020). An ecological future for weed science to sustain crop production and the environment, a review. *Agronomy for Sustainable Development*, 40(4), 1-29.

Majaliwa, J. G. M., Twongyirwe, R., Nyenje, R., Oluka, M., Ongom, B., Sirike, J., & Barasa, B. (2010), The effect of land cover change on soil properties around Kibale National Park in South Western Uganda. *Applied and Environmental Soil Science*, 2010.

Malhotra, S. K. (2017). Horticultural crops and climate change: A review. *The Indian Journal of Agricultural Sciences*, *87*(1), 12-22.Academic Press.

Mbowa, S., & Mwesigye, F. (2016). The Seed Potato Gap in Uganda: An Investment Opportunity, and a Challenge for Value Addition. *EPRC (Economic Policy Research Centre), Kampala, Uganda*.

Muhinyuza, J. B., Shimelis, H., Melis, R., Sibiya, J., & Nzaramba, M. N. (2016), Combining ability analysis of yield and late blight ['Phytophthora infestans'(Mont.) de Bary] resistance of potato germplasm in Rwanda. *Australian Journal of Crop Science*, 10(6), 799.

Muthoni, J., & Shimelis, H. (2020) Heat and drought stress and their implications on potato production under dry African tropics, *Australian Journal of Crop Science*, 14(9), 1405-1414.

Muthoni, J., Shimelis, H., & Melis, R. (2015). Combining ability analysis of tuber yield and related traits and bacterial wilt ('Ralstonia solanacearum') resistance in potato. *Australian Journal of Crop Science*, *9*(5), 401-412.

Mutimawurugo, M. C., Wagara, I. N., Muhinyuza, J. B., & Ogweno, J. O. (2019). Virulence and characterization of isolates of potato bacterial wilt caused by Ralstonia solanacearum (Smith) in Rwanda. *African Journal of Agricultural Research*, *14*(6), 311-320.

Nakitandwe, J., Adipala, E., El-Bedewy, R., Wagoire, W., & Lemaga, B. (2003). Inter-relationships among potato traits and their significance in determining tuber yield.

Namugga, P., Melis, R., Sibiya, J., & Barekye, A. (2017). Participatory assessment of potato farming systems, production constraints and cultivar preferences in Uganda. *Australian Journal of Crop Science*, 11(8).

Namugga, P., Sibiya, J., Melis, R., & Barekye, A. (2020). Combining ability analysis of yield and resistance to late blight disease caused by Phytophthora infestans. Uganda. *Australian Journal of Crop Science*, 14(10), 1637-1644.

Njoroge, A.W.; Andersson, B.; Lees, A.K.; Mutai, C.; Forbes, G.A.; Yuen, J.E.; Pelle, R. (2019) Genotyping of Phytophthora infestans in Eastern Africa reveals a dominating invasive European lineage. *Phytopathology*, 109, 670-680.

Obidiegwu, J. E., Bryan, G. J., Jones, H. G., & Prashar, A. (2015). Coping with drought: stress and adaptive responses in potato and perspectives for improvement, *Frontiers in Plant Science*, 6, and 542.

Oliveira, J. S., Moot, D. J., & Brown, H. E. (2014). Seed potato physiological age and crop establishment. In *Agronomy Society of NewZealand* (Vol. 44, pp. 85-93).

Omomowo, O. I., & Babalola, O. O. (2021). Constraints and prospects of improving cowpea productivity to ensure food, nutritional security and environmental sustainability. *Frontiers in Plant Science*, 12.

Oraby, H., Lachance, A., & Desjardins, Y. (2015). A low nutrient solution temperature and the application of stress treatments increase potato mini-tubers production in an aeroponic system. *American Journal of Potato Research*, 92(3), 387-397.

Orsini, F., Kahane, R., Nono-Womdim, R., & Gianquinto, G. (2013). Urban agriculture in the developing world: a review. *Agronomy for sustainable development*, *33*, 695-720.

Owusu, G. A., Nyadanu, D., Obeng-Antwi, K., Amoah, R. A., Danso, F. C., & Amissah, S. (2017). Estimating gene action, combining ability and heterosis for grain yield and agronomic traits in extra-early maturing yellow maize single-crosses under three agro.

Pino, M. T., & Vergara, C. (2021). Red and purple flesh potatoes a healthy and attractive alternative associated with new market trends. *Solanum tuberosum-a Promising Crop for Starvation Problem*.

Razukas, A., Jankauskiene, Z., Jundulas, J., & Asakaviciute, R. (2009). Research of technical crops (potato and flax) genetic resources in Lithuania. *Agronomy Research*, *7*(1), 59-72.

Reddy, B. J., Mandal, R., Chakroborty, M., Hijam, L., & Dutta, P. (2018). A review on potato (Solanum tuberosum L.) and its genetic diversity. *International Journal of Genetics, ISSN*, 0975-2862.

Schumacher, C., Thümecke, S., Schilling, F., Köhl, K., Kopka, J., Sprenger, H., ... & Horn, R. (2021). Genome-wide approach to identify quantitative trait loci for drought tolerance in tetraploid potato (Solanum tuberosum L.). *International Journal of Molecular Sciences*, *22*(11), 6123.

Singh, J., & Kaur, L. (Eds.). (2016). *Advances in potato chemistry and technology*. Academic press.

Smith, R., Kelly, B., Yeatman, H., & Boyland, E. (2019). Food marketing influences children's attitudes, preferences and consumption: a systematic critical review. *Nutrients*, *11*(4), 875.

Soison, B., Jangchud, K., Jangchud, A., Harnsilawat, T., & Piyachomkwan, K. (2015). Characterization of starch in relation to flesh colors of sweet potato varieties. *International Food Research Journal*, *22*(6), 2302.

Stockem, J., de Vries, M., van Nieuwenhuizen, E., Lindhout, P., & Struik, P. C. (2020). Contribution and stability of yield components of diploid hybrid potato, *Potato Research*, 63(3), 345-366.

Suarez, T. (2012). Early mapping of Southeast Asia: the epic story of seafarers, adventurers, and cartographers who first mapped the regions between China and India. Tuttle Publishing.

Sultana, s. (2015). Genetic variability, correlation and path analysis in f4 generation of brassica napus l (doctoral dissertation, department of genetics and plant breeding, Sher-e-bangla Nagar, Dhaka-1207).

Thomson, K. J. (2009). The State of Food and Agriculture 2008: Biofuels: Prospects, Risks and Opportunities. Food and Agriculture Organisation of the United Nations. xi+ 128 pp. Rome: FAO (2008). $65.00. ISBN 078-92-5-105980-7, ISSN 0081-4539. Available at: http://www. fao. org/docrep/011/i0100e/i0100e00. htm. *The Journal of Agricultural Science*, *147*(4), 503-503.

Van der Waals, J. E., Steyn, J. M., Franke, A. C., & Haverkort, A. J. (2016). Grower perceptions of biotic and abiotic risks of potato production in South Africa. *Crop Protection*, *83*, 44-53.

Varela, M., Crossa, J., Rane, J., Joshi, A. K., & Trethowan, R. (2006). Analysis of a three-way interaction including multi-attributes. *Australian Journal of Agricultural Research*, *57*(11), 1185-1193.

Von Ende, C. N. (2020). Repeated-measures analysis: growth and other time-dependent measures. In Design and analysis of ecological experiments (pp. 113-137), Chapman and Hall/CRC.

Wang-Pruski, G. (2018). *Achieving sustainable cultivation of potatoes Volume 1: Breeding improved varieties*. Burleigh Dodds Science Publishing.

Wijesinha-Bettoni, R., & Mouillé, B. (2019). The contribution of potatoes to global food security, nutrition and healthy diets. *American Journal of Potato Research*, *96*, 139-149.

Xu, Y. (2016). Envirotyping for deciphering environmental impacts on crop plants. *Theoretical and Applied Genetics*, *129*, 653-673.

Yan WeiKai, Y. W., & Hunt, L. A. (2002). Biplot analysis of multi-environment trial data. In *Quantitative genetics, genomics and plant breeding* (pp. 289-303). Wallingford UK: CABI Publishing.

Yang, M., Zhu, L., Pan, C., Xu, L., Liu, Y., Ke, W., et al. (2015). Transcriptomic analysis of the regulation of rhizome formation in temperate and tropical lotus (Nelumbo nucifera). *Scientific reports*, 5(1), 1-17.

Zaheer, K., & Akhtar, M. H. (2016). Potato production, usage, and nutrition—a review. *Critical reviews in food science and nutrition*, 56(5), 711-721.

Zhao, P., & Xu, S. (2012). Genotype by environment interaction of quantitative traits: a case study in barley. *G3: Genes| Genomes| Genetics*, *2*(7), 779-788.