Mekelle University

Evaluation of potato (*Solanum tuberosum* L) genotypes for yield and agronomic traits under irrigation in southern Tigray, Ethiopia

By

Desta Abadi

A thesis submitted in partial fulfillment of the requirements for the

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DECLARATION

I, Desta Abadi Alemu, here by present my thesis entitled: **Evaluation of potato (*Solanum tuberosum* L) genotypes for yield and agronomic traits under irrigation in southern Tigray, Ethiopia**, in partial fulfillment of the requirement for the degree of Masters in Horticulture for consideration by the Plant and Horticultural Sciences Department, College of Dryland Agriculture and Natural Resources, Mekelle University. I declare that this thesis is the product of my own efforts, and the materials used in the thesis are appropriately acknowledged, no other person has published a similar study which I might have copied, and at no stage will this be published without my consent and that of the Plant and Horticultural Sciences Department.

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TABLE OF CONTENTS

Contents **page**

EVALUATION OF POTATO (*Solanum tuberosum*. L) GENOTYPES FOR YIELD AND AGRONOMIC TRAITS UNDER IRRIGATION IN SOUTHERN TIGRAY, ETHIOPIA.

ABSTRACT

Potato (Solanum tuberosum L.) is most important food crop in Ethiopia, and understanding its genetic variability is crucial for improvement efforts. However, research evaluating genotypes for yield and agronomic traits under irrigation in specific regions remains limited. This study aimed to assess the performance of 15 potato genotypes across 16 quantitative traits under irrigated conditions in Maichew and Emba-Alaje woredas during the 2024/2025. Randomized Complete Block design, with three replications was employed, utilizing plots of 3m x 3m with a spacing of 75 cm between rows and 30 cm between plants. Significant interaction effect was observed among the genotypes for most traits. The highest total tuber yields were recorded for G12 CIP302498.72 (48.94 t ha^{-1}*), G3 CIP397029.21 (48.71 t* ha^{-1}*) and G2 CIP312923.637 (48.49 t* ha^{-1}*) at Maichew while the lowest yield was noted for G13 CIP312920.599 (14.27 t* ha^{-1}*) at Emba Alaje. Correlation analysis revealed positive associations between total tuber yield and Plant height (r=0.43), marketable tuber yield (r=0.99), unmarketable tuber number per hill (r=0.34), marketable tuber number per hill (r=0.68) and total tuber number per hill (r=0.58). Conversely, a negative correlation was observed with days to maturity (r= -0.47). Principal component analysis results revealed that the first three components accounted for 75.09% of the total variability (PC1:37.16%, PC2:23.98%, PC3:13.98%). Hierarchical clustering grouped the genotypes into five distinct clusters based on yield and quality traits. These findings highlight significant genetic variability among the evaluated potato genotypes. Given that the study was conducted over a single growing season at two locations, further research involving multiple seasons and locations is recommended to validate these results and assess factors such as late blight resistance in the southern zone of Tigray and similar agro-ecological areas.*

Key words: *Potato, Genotype, Correlation, Clustering, Total tuber yield.*

DEDICATION

This thesis manuscript is dedicated to my mother, w/ro Birzaf Abrha and my father Mr Abadi Alemu.

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LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX TABLES

LIST OF APPENDEX FIGURE

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CIP	International Potato Center
Cm	Centimeter
CSA	Central Statistical Agency
CSS	Central Statistical service
FAO	Food and Agriculture Organization
HARC	Holeta Agricultural Research Center
Kg ha^{-1}	kilogram per hectare
Mm	Millimeter
PCA	Principal component analysis
PCV	Phenotypic Coefficient of Variability
TARI	Tigray Agricultural research Institute
T ha^{-1}	Ton per hectare

BIOGRAPHICAL SKETCH

Desta Abadi is born in 1993 in Bora Woreda, located in the Southern Zone of Tigray Region, Ethiopia. He attended his elementary school education at Waereb Dequali complete elementary school from 1999-2004. He then continued his secondary education at Adishihu Senior Secondary School, where he completed high school in 2010. In 2011 he enrolled at Maichew Agricultural Poly Technic College and graduated in July, 2012 with a Diploma in Horticulture. After graduation he was employed as Instructor in Horticulture in the Department of Plant Science at Maichew Agricultural Poly Technic College in the Southern Zone of Tigray in 2013. Alongside his work he pursued further studies at the College of Agriculture and Environmental Science at Adigrat University. He joined summer program in 2013 and earned Bachelor of Science (BSc) degree in plant science in October 2018. he has been working at the college continuously since 2013. In 2021, he enrolled in the regular post-graduate Studies program at Mekelle University to pursue a Master of Science (MSc) degree in Horticulture.

CHAPTER ONE: INTRODUCTION

1.1. Background information

Potato is the world's third most important food crop, after rice and wheat, for human consumption. It is cultivated on an estimated 20 million hectares of farmland worldwide, producing around 376 million tons and consumed in more than 100 countries, which is a major milestone in the agriculture sector FAOSTAT, (2023).

Global statistics also show that potato production in developing countries such as Africa has increased significantly, reaching 26 million tons. In Africa, potato production and growing areas have more than doubled in the past two decades. It confirms the growing importance of potatoes as a source of food, jobs and income in Asia, Africa and Latin America (Devaux et al., 2021). Potatoes thus play a major role in maximizing agricultural productivity and in feeding the growing population.

Potato is a nutritionally balanced food, which provides a high calorie intake and a substantial number of vitamins. It is rich in protein, calcium, potassium, and vitamins, and has an especially good amino acid balance (Birch et al., 2012). In addition, potatoes are used for several industrial purposes to produce processed products such as French fries, chips, dehydrated potatoes and to produce starch and alcohol. Potato starch (farina) is used in laundries and for sizing yarn in textile mills. Potatoes are also used to produce dextrin and glucose. The economic contribution of the crop in terms of employment, income generation, export earnings and ultimately to the national income is significant (Lutaladio and Castaidi, 2009).

In Tigray, potatoes have been one of the most important crops for several years. The agro-climatic conditions of the region, particularly the eastern, southern and central zones, are ideal for good quality potato production. The area devoted to potato cultivation increased from 54,006 ha in 2010 to 66,923 ha in 2016. This is the first among root crops in Ethiopia in terms of both area coverage and total production CSA, (2017). Likewise, the area devoted to potato cultivation in the Tigray region increased from 395 ha in 2015/16 to 622 ha in the main growing season of 2016/17.

1.2. Statement of the problem

In Ethiopia, potato is considered one of the most important food crops that contributes not only to the mitigation of food security but also serving as an important cash-generating crop. Most Ethiopians rely on cereal crops, with root and tuber crops serving as key non-cereal staples. The food potential of the tuber crops such as potato has not been adequately exploited. As a food crop, the potato has a high potential to supply a cheap and quality food within a relatively short period.

Potato production in the Southern Zone of Tigray, Ethiopia, faces numerous challenges despite its potential for improving food security and livelihoods. The sector has been significantly impacted by the 2020-2022 war, which disrupted agricultural activities, destroyed infrastructure, and reduced farmers' access to seeds and inputs. This has caused a drop in potato production and market activity. Before the conflict, potato was an important crop, but now only 30% of the irrigable land is being used, down from 70% pre-conflict. (Mwambi et al., 2024).

Southern Tigray with its highland area covering up to 3600 m.a.s.l is favorable for potato production. Currently the farmers in southern Tigray are producing high amount of potato seed tubers. The potato production is extending into several farmers because of its advantages of high yield per unit land as well as its significance in terms of income as it is sold as seed tubers. Recently its production is also expanded to the lowland parts of southern Tigray. Small holder farmers and investors in the Raya valley produce large amount of potato. However, the productivity of the crop in the region is far below its potential with the productivity of 8.9 t ha^{-1} as compared to the national (13.62 t ha^{-1}) and world average (21 t ha^{-1}) (FAO 2023) due to lack of high yielding varieties, low quality seed tubers, access to seed tuber and area specific management practices.

In addition, before the war, farmers were getting accessed certified potato seed tubers from NGOs and cooperatives like Shewit in Atsbi Wemberta and Hashenge in Ofla, supported by the MU-ISSD project and other actors. Now these associations are out of services. So, farmers rely on informal seed systems, such as local or farmer-to-farmer exchange, the improved varieties often mixed with local ones and no pure improved seeds available.

1.3. Justification

Potato has high potential to contribute to food security and income generation in southern Tigray. However, the region suffers from low productivity due to poor seed quality, old local varieties, and the absence of improved, location-specific genotypes. The recent conflict has worsened these issues by disrupting certified seed supply systems, leaving farmers dependent on informal, low-quality seed sources.

Given the region's diverse agro-ecology ranging from highlands like Maichew and Ayba to expanding lowland areas in Raya Valley. However, there is a critical gap in identifying and promoting high-yielding and well-adapted potato genotypes suitable for these diverse environments under irrigation.

Evaluating potato genotypes across multiple locations is essential to identify genotypes with stable performance and better adaptability. Moreover, studying the interaction effect between genotype and environment (location) helps in selecting genotypes that are not only high-yielding but also location-specific in performance. This research contributes in improving productivity, ensuring seed quality in southern Tigray.

Therefore, the aim of this study was to address existing productivity constraints by evaluating potato genotypes for their agronomic performance and yield under irrigation in key areas of Southern Tigray. The findings are expected to support variety selection, improve seed tuber supply, and ultimately enhance the livelihoods of smallholder farmers in post-conflict recovery efforts.

1.4. Objective

General objective

- ✓ To evaluate the yield and agronomic traits of various potato genotypes under irrigated conditions in the Southern Zone of Tigray.

Specific objective

- ✓ To identify and characterize potato genotypes for yield in multiple locations.
- ✓ To investigate the dynamic interaction between potato genotypes and distinct geographical locations
- ✓ To estimate the correlations among yield and its contributing traits

1.5. Hypothesis

Null Hypothesis (H_0): There is no significant difference among the evaluated potato genotypes in terms of yield and agronomic traits under irrigation in southern Tigray.

There is no significant interaction effect between genotype and location on the yield and agronomic traits of potato (*Solanum tuberosum* L.) under irrigation in southern Tigray, Ethiopia.

Alternative Hypothesis (H_1): There are significant differences among the evaluated potato genotypes in terms of yield and agronomic traits under irrigation in southern Tigray.

There is a significant interaction effect between genotype and location on the yield and agronomic traits of potato (*Solanum tuberosum* L.) under irrigation in southern Tigray, Ethiopia.

1.6. Significance of the study

Potato is an important crop for the southern zone of Tigray. However, there are various problems when growing potatoes that affect the yield and quality of this crop. In southern Tigray, the potato is a cash and food crop with great potential to improve the livelihoods of smallholder farmers in the highlands of southern Tigray. Its potential for high yields, early maturity and excellent nutritional value gives potato great potential for improving food security, increasing household income and reducing poverty in low-income farmers such as southern Tigray. Potatoes are a valuable source of food and play a critical role in food security in southern Tigray. They are staple food for many households in the region and provide important nutrients such as carbohydrates, vitamins and minerals. Potato cultivation helps diversify local diets and improve nutritional outcomes, particularly in areas where other food crops may face challenges. In this context, the identification of high yield and resistance to late blight increases both the qualitative and quantitative product of the crop. The document can also be used as a base or reference material for further research, teaching and learning processes and development activities by selecting the best performing potato genotypes.

CHAPTER TWO: LITERATURE REVIEW

2.1. The Potato Crop with its Origin and Distribution

Potato (*Solanum tuberosum* L.) is a major vegetable crop in the world because of its high productivity, nutritional value, low costs and easy preparation (Ebrahim, 2019). Potatoes are annual herbaceous plants cultivated in temperate, subtropical and tropical climates. It is essentially a cold weather crop, producing edible underground bulbs used as vegetables. It belongs to the *Solanaceae* family, the *Solanaceae* order, the genus Solanum, and the Solanaceae family comprises 102 genera and 2,280 species (Reddy et al., 2018). Potatoes were domesticated in the Andes of southern Peru about 10 000 years ago. Solanum tuberosum arose from wild species in the Solanum brevicaule Bitter complex (Ovchinnikova et al., 2011).

The potato (*Solanum tuberosum* L.*)* is a species that can be traced back to pre-Columbian hill tribes cultivated in the Andes and Chile. These grasslands occur throughout the Andes, from western Venezuela to northern Argentina and southern Chile, and show a wide diversity of morphological and genetic variation (Montero et al., 2021). The Andes in South America are considered the main center of origin for potatoes and their wild relatives. Potatoes were first domesticated between 6 and 10,000 years ago in central South America around Lake Titicaca (Montero et al., 2021). The wild ancestors of these races have long been controversial, but all the speculation points to the Solanum brevicaule complex, a collection of roughly 20 species that are morphologically similar. Cultivated by South American Indians for thousands of years, tubers are consumed as a popular foodstuff (Ebrahim, 2019; Montero et al., 2021).

2.2. Potato Production in the World

Potato is grown in more than 150 countries under temperate, subtropical and tropical conditions and represent a staple food for approximately one billion people in the world, about half of whom live in developing countries (Placide et al., 2022). The cultivated potato of world trade, *Solanum tuberosum* L., is a staple food crop grown and consumed worldwide and represents a staple food and primary source of income for many societies. Potatoes include native, cultivated (landraces), and wild species (Solanum, section Petota) (Castañeda-Álvarez et al., 2016).

Landrace populations in Mexico and Central America are recent, post-Columbian introductions. The landraces are highly diverse, with a great variety of shapes and skin and tuber colors not often seen in modern improved varieties. It is currently grown on an estimated 19.25 million hectares of farmland globally, with a production worldwide of 376.89 million tons and productivity of 19.58 t ha^{-1} Food and Agriculture Organization of the United Nations, (2020).

According to global statistics, the top ten potato-producing countries based on the total area under cultivation are China, India, Ukraine, the Russian Federation, Bangladesh, the United States of America, Peru, Nigeria, Germany, and Belarus. These countries dedicate the largest land areas to potato farming, reflecting the crop's strategic importance to their agricultural sectors. However, when ranked by total production volume, the leading producers are China, India, Ukraine, the Russian Federation, the United States of America, Germany, Bangladesh, France, Poland, and the Netherlands. These countries contribute significantly to global potato output, with China and India alone accounting for a substantial share. The average productivity among these leading producers is reported to be 35.91 tons per hectare, indicating efficient and high-yielding production systems, especially in countries like the Netherlands and Germany (Perez et al., 2022, as cited by LIBASE, 2023). This data highlights both the geographical spread and the technological advancements that contribute to global potato production.

2.3. Potato Production and Productivity in Ethiopia

Potato is a valuable crop for Ethiopian smallholder farmers, serving as both a cash crop and a food security crop. Because of rising demand and developing markets, it is one of the most extensively produced root and tuber crops in the country, providing a significant chance for resource-poor farmers to generate additional money (Bekele et al., 2011; Degebasa et al., 2020). It is a short-term crop that matures within short period of time. It is the most widely grown tuber crop in the high and mid altitude areas of Ethiopia (Degebasa et al., 2020).

As of 2022, Ethiopia's potato cultivation covered approximately 74,727 hectares, yielding around 1.29 million tons of potatoes. This results in an average productivity of about 17.3 tons per hectare, marking an improvement from the 13.92 tons per hectare reported in the 2017/2018 production year.

This upward trend in potato productivity reflects ongoing efforts to enhance agricultural practices, including the adoption of improved seed varieties, better irrigation techniques, and integrated nutrient management. Such advancements are crucial for bolstering food security and supporting the livelihoods of smallholder farmers across Ethiopia.

Potato is currently grown in four primary geographical regions in Ethiopia. These regions are the Central, Eastern, North-Western, and South regions. These accounts for roughly 83 percent of the country’s potato producing areas (Wassihun et al., 2019). Its production is hindered by a variety of factors, which results in low yields. These factors include lack of high-yielding, late blight tolerant varieties, low soil fertility, climate constraints, insufficient seeds, poor cultural practices, poor post-harvest management and storage issues, high farm input prices diseases, and insect pests. Ethiopia ranks eighth among potato-producing countries in Africa, but its productivity is much lower compared to the world's top ten potato-producing countries. Abebe, (2020).

2.4. Major Potato Production Area in Ethiopia

In Ethiopia, the area under potato cultivation has increased by more than fivefold from 30 000 ha in the 1970s (Kolech et al., 2016) to over 169 000 ha (Wassihun et al., 2019). The highland climate of Ethiopia is well suited to the cultivation of potatoes. Potatoes are a very important food and cash crop, particularly in the high and medium-altitude regions of Ethiopia. In most developing countries, and especially in urban areas, the rising level of income is driving a shift in nutrition towards more energy-intensive food and processed products (Reddy et al., 2018).

In Ethiopia, potato is grown in a broad range of agro-ecological zones, for the duration of the year. the use of different growing practices and is considered a "hunger breaking crop" due to the fact it can be grown and harvested when cereals don't mature for consumption. Indeed, potato is the solely meals crop grown to any massive extent in the dry season where rain-fall is erratic and unpredictable in the months of March through May (Kolech et al., 2015; Degebasa, 2019).

2.5. Current Status of Potato Genetic Variability in Ethiopia

The past few decades have seen a dramatic expand in potato production and demand in many developing countries Lema and Zewdu, (2016). Ethiopia is one of Africa's top potato growers, with 70 percent of fertile terrain over 1500 meters ideal for potato farming Lema and Zewdu, (2016). The first widely grown variety, AL-624, was released in 1987.since then, more than 32 potato varieties were developed and released where as eight potato varieties developed in Europe were also evaluated for their adaptation, yield and registered for production in the country by agricultural research centers and Haramaya University Degebasa, (2019). The high yield potential of potato and its plasticity to environmental regimes makes it as one of the best crops for food and nutrition security in Eastern Africa (Kolech et al., 2015).

Currently, there is a total of more than 2500 germplasm of potato on hand at Holeta and Adet research centers. Nationally, about seventy-seven percent of Ethiopian potato land is planted by those available cultivars each year (Kolech et al., 2015). But such cultivars are low yielding. Because of the perception of poor yield, local cultivars have obtained relatively little interest from the research community. Instead, cultivar improvement has focused on evaluating clones developed from external sources, particularly the International Potato Center (CIP) (Kolech et al., 2015). Researchers in Ethiopia received the germplasm for selection in the form of advanced clones, tuber families, and proper potato seed.

Genetic gains for potato breeding in the USA since the late 19th century until the early 1990s were noted only for early maturity and overall tuber appearance but not for tuber yield per se, while chip-processing ability and dry matter content improved only for white-skin cultivars Ortiz, (2020).

2.6. Estimation of Genotypic and Phenotypic Variability

2.6.1. Genetic Variation in potato

Variation is the occurrence of differences among individuals due to their genetic makeup and/ or the environment in which they are raised. Thus, phenotypic variability is the observable variation present in a character in a population; it includes both genotypic and environmental variation and as a result, its magnitude differs under different environmental conditions. Genotypic variability, on the other hand, is the component of variation, which is due to the genotypic differences among individuals within a population. It is used for a specific characteristic, where these genetic differences reside in one or more DNA sequences (Swarup et al., 2021).

In order to progress rapid and efficient crop improvement through plant breeding there should be genetic variability because superior genotypes can be selected from different population. Plant breeders are mostly interested in genetic variation since proper management of such variation could result in remarkable impact in the performance of the crop. The existences of genetic variability among individuals due to genetic composition difference have large importance in plant breeding program because the permanent gain in the performance of plant can be assured through proper management of diversity Fasil, (2019).

Genetic variability studies provide basic information concerning genetic properties of population following which breeding methods could be formulated for future improvement of the crop (Fasil, 2019). Genetic parameters like genotypic and phenotypic coefficient of variation had also an advantage in detecting the amount of genetic variation exist in the genotypes. Genetic variability study for agronomic traits is a key component of the breeding program for boarding the genetic pool of crop. Once genetic variability of certain crops has been successfully determined crop improvement is easy through the use of appropriate selection methods on yield components. Since, they are easily inherited than total yield itself Temesgen, (2007).

Selection is effective when there is a significant amount of genetic variability among the individuals in a population. Understanding the genetic and phenotypic variation, along with estimating heritability, helps researchers improve crops for desired traits. This is because genetic and phenotypic differences mainly drive yield improvement, while environmental factors can only be partially controlled. Generally, the achievement of crop improvement through breeding program largely relies on the extent of genetic and phenotypic variability existed among individuals in the population Fasil, (2019).

The most common goals for potato genetic improvement have been productivity, quality for diverse end-users, and resilience in the target population for adverse situations under a changing climate. However, the qualities that determine such attributes may not always exhibit positive relationships, reducing the amount of beneficial genetic variation available for selection. The true variance and covariance components are unknown, but multi-site trial data can be used to estimate them. They are used to calculate trait heritability and correlations between traits. This understanding will help guide the potato breeding strategy, and how to apply selection for desired features in the target population of settings (Ortiz et al., 2021). Estimation of variability for desirable traits is important in any systematic crop breeding program. Genetic variability is the prime interest of plant breeders because proper management of this diversity can produce permanent gains in the performance of the plant Ali, (2020).

CHAPTER THREE: MATERIALS AND METHODS

3.1. Description of the Study Area

The study was conducted in Maichew and Emba Alaje woredas (Ayba) in the southern highlands of the Tigray region, Ethiopia, during irrigation season of 2024. The first site was selected within the campus of Maichew Agricultural Polytechnic College, situated about 662 km north of Addis Ababa and 120 km south of Mekelle, the regional capital. This site, at an altitude of 2,432 meters above sea level and has average annual temperatures ranging from 12.07 to 24.96 ºC and receives 600 to 800 mm of rainfall annually (Mekelle Meteorology Station, 2008). The local economy relies on traditional subsistence mixed farming, integrating livestock and crop farming. Crop production primarily depends on rainfall, though there is a growing trend toward irrigation due to variable rainfall patterns. Major crops include maize, teff, wheat, barley, onion, and tomato.

The second study site was at Tabia Ayba which is located in the highland area of Northern Ethiopia, specifically in the Southern Zone of Tigray, within the Emba Alaje District. Its altitude is 2350 meters above sea level (m.a.s.l). The area experiences a bi-modal rainfall pattern, with short rains (Belg) from March to May and the main rainy season (Meher) from June to September. The average daily temperature ranges from 9 to 23 ºC. Major crops include sorghum, teff, maize, wheat, barley, faba bean, field pea, linseed, onion, pepper, and cabbage.

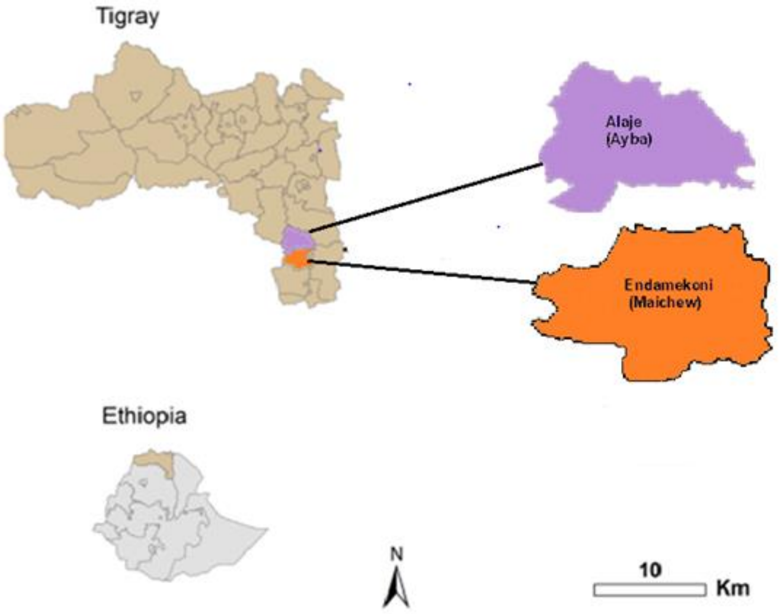


Fig 1: Map of the study area Maichew & Emba Alaje Woreda (Ayba)

3.2. Plant Materials

In this study, a total of 15 potato genotypes were used consisting of 13 advanced genotypes and 2 recently nationally released potato varieties as standard checks. The names of the genotypes and their source are presented in Table 1.

Table 1. List of the experimental materials included in the study

N<u>o</u>	Genotypes	Genotype Code	Source	Remarks
1	CIP30299.2	G1	HARC	Accession
2	CIP312923.637	G2	HARC	Accession
3	CIP397029.21	G3	HARC	Accession
4	CIP312921.05	G4	HARC	Accession
5	CIP396279.48	G5	HARC	Accession
6	CIP312920.528	G6	HARC	Accession
7	CIP312921.525	G7	HARC	Accession
8	CIP314030.2	G8	HARC	Accession
9	CIP392657.171	G9	HARC	Accession
10	CIP393371.164	G10	HARC	Accession
11	CIP312927.523	G11	HARC	Accession
12	CIP302498.72	G12	HARC	Accession
13	CIP312920.599	G13	HARC	Accession
14	Burka	G14	HARC	Released variety
15	Gudene	G15	HARC	Released variety

3.3. Treatments, Experimental Design and Trial Management

The experiments were conducted during the 2024 cropping season using a Randomized Complete Block Design (RCBD) with three replicates across two different locations. Each plot measured 3 m × 3 m (9 m²) and consisted of four rows. Each row accommodated 10 plants, resulting in a total of 40 plants per plot. the spacing between plots was 1 meter, while the distance between blocks was 1.5 meters. Well-germinated potato seed tubers of each genotype were hand-planted in furrows approximately 15 cm deep, with 75 cm between rows and 30 cm between plants. Fertilizer application followed recommended rates: 195 kg ha^{-1} of NPS (Nitrogen, Phosphorus, and Sulfur) and 165 ha^{-1} of urea per hectare. The urea was applied in two stages, 50% at planting and the remaining 50% during the vegetative stage after 20 days emergence, while all the NPS was applied at planting.

3.4. Experimental Procedure

Land preparation: Prior to planting, the land was prepared using oxen. The experimental plots were cultivated to a depth of 25-30 cm using oxen. The land was leveled, and ridges were made according to the proposed planting spacing's by hand.

Planting: A medium size well sprouted tubers were planted in January 30/2024 across both locations. The seed tubers of all genotypes were obtained from Holeta Agricultural Research Center.

Other cultural practices: Weeding, cultivation and earthing-up were done at the appropriate time to facilitate root, stolon and tuber growth. Weed was achieved through hoeing. The earthing-up was done 3 times. The first, second and third earthing were done 20, 45 and 60 days after emergence respectively to prevent exposure of tubers to direct sunlight, for promoting tuber bulking and for ease of harvesting. Other cultural practices were applied as per the recommendation made for the crop.

Crop protection: Potato plants were treated with MATCO fungicide (Mancozeb 64%+Metalaxyl 8%) at the rate of 2.5 kg ha^{-1} diluted at 1000 liter of water at seven days interval to control late blight disease.

Harvesting: When yellowing or senescence was observed on the lower leaves, the haulm was mowed two weeks before harvesting to thicken tuber periderm to avoid bruising and skinning during harvesting and post-harvest handling. The plants growing in the two border rows as well as those growing at both ends of each row were left from harvesting to avoid border effects.

3.5. Data Collection Procedures

Growth Parameters

Days to 50% flowering: the number of days to flowering was recorded by counting the numbers of days from planting to the flowering until 50% of the plant populations in each plot had bloomed (Tessema et al., 2019).

Days to 90% maturity: It was determined by counting the number of days from planting until more than 90% of the plants exhibited yellowing Assefa, (2023).

Plant height (cm): was measured by taking five plants per plot from two middle rows as a distance in centimeter from the soil surface to the topmost growth point at physiological maturity (Abewoy et al., 2022).

Branch number/hills: the actual number of branches per hill was recorded by taking five plants per plot as the average branch count of five hills per plot at maturity. Only branches that emerged independently above the soil as single stems were considered as number of branches (Asefa et al., 2019).

Yield and Yield Components

Tuber Length (mm): Length of ten marketable tubers from each plot for each treatment were measured at matured stage using venire caliper and mean values was taken.

Tuber Diameter (mm): Tuber diameter was measured from ten marketable potato tuber of sample plants from each plot at matured stage and from the central part of the tuber using venire caliper and mean values were recorded (Abewoy et al., 2022).

Average tuber weight/hill (g): was determined by dividing the total fresh tuber yield to the respective total number of hills which was harvested from five plants (Abewoy et al., 2022).

Total tuber number/hill: was determined as the sum of marketable tuber number and unmarketable tuber number per hill which was harvested from five plants.

Number of marketable tuber/hills: was counted as marketable based on their size category, which is greater or equal to 25g Bilate and Mulualem, (2016).

Number of unmarketable tuber/hills: was counted as unmarketable based on their size category, which is < 25g included disease and insect attack considered as unmarketable Bilate and Mulualem, (2016).

Total tuber yield (t ha^{-1}): was determined as the sum of the weights of marketable and unmarketable tubers from the net plot area of two middle rows and was calculated on base of ton per hectare.

Marketable tuber yield (t ha^{-1}): was free from diseases, insect pests, and greater than or equal to 25 g Bilate and Mulualem, (2016) in weight was determined as ton per hectare.

Unmarketable tuber yield (t ha^{-1}): was determined from counted number of tubers and weighted that was diseased, insect attacked and small-sized (< 25g) and calculated as t ha^{-1} Bilate and Mulualem, (2016).

Tuber quality parameter

Specific gravity of tubers (gcm-^{3}): This was determined by the weight in air/weight in water method. A five kg tuber of all shapes and sizes was randomly taken from each plot and was washed with water. Then it was weighted first in air followed by weighing in water. Thereafter, specific gravity was calculated using the following formula (Bekele and Haile 2018).

$$\text{Specific gravity of tubers} = \frac{\text{weight in air}}{\text{weight in air} - \text{weight in water}}$$

Tuber dry matter content (%): Five potato tubers was randomly selected from each plot, chopped into small 1-2 cm cubes, mixed thoroughly and two fresh sub-samples each weighing 200 g were weighed. Each sub-sample was placed in a paper bag and put in an oven until a constant weight was attained at 70°C. Each sub-sample was immediately weighed, and the mean recorded as dry weight. Percent dry matter content for each subsample was calculated based on the formula described by Bekele and Haile, (2018).

$$\text{Tuber dry matter content (\%)} = \frac{\text{Tuber dry weight (g)}}{\text{Tuber fresh weight (g)}} \times 100$$

Total starch content (%): The percentage of starch was calculated from the specific gravity where specific gravity was determined as indicated above by the weight in air and weight in water method. Starch (% or g/100 g) =17.546 +199.07 × (specificgravity-1.0988) Smith and Talburt, (1959) as cited by Yildrim and Tokusoglu, (2005).

3.6. Methods of Data Analysis

All relevant data collected from the experimental plots were subjected to analysis of variances (ANOVA), which was computed by using GenStat statistical software (18th edition) and the differences between treatment means were computed by means of Duncan's Multiple Range Test (DMRT) at a 5% level of significance because it is a widely used procedure for comparing all pairs of means. The data has been standardized to mean 0 and standard deviation 1, prior to cluster analysis. A correlation matrix was used as an input for the PCA. Correlation analysis was also carried out using the GenStat statistical software. The strength of the correlation was interpreted based on the absolute value of the Pearson correlation coefficient (r), where: $r \geq 0.7$ indicates a strong correlation, $0.4 \leq r < 0.7$ indicates a moderate (medium) correlation and $r < 0.4$ indicates a weak correlation Dancey and Reidy, (2007).

CHAPTER FOUR: RESULT

4.1. Analysis of variances for phenology, yield & quality related traits

The ANOVA results indicated significant effects of genotypes, locations, and their interactions on the measured parameters (Table2). The notable significance between interactions of genotypes × locations (environment) suggest that agronomic traits of the genotypes varied across the tested environments. For plant height (PH), both genotypes and location exhibited highly significant effects ($p \leq 0.01$), indicating substantial differences among genotypes and a strong influence of environmental conditions. Furthermore, the significant treatment × location interaction ($p \leq 0.01$) implies that the response of plant height to genotypes varies across different locations.

Both the genotype and location main effects on days to flowering (DF) and days to maturity (DM), were highly significant, indicating substantial variability due to these factors. However, while the genotype × location interaction was marginally significant for flowering ($p \leq 0.05$), it was not significant for maturity. This suggests that the genotype effects on maturity remain consistent across different locations.

In terms of tuber traits, including tuber diameter (TD) and tuber length (TL), genotypes showed highly significant effects, confirming considerable variability among them. While location had a significant impact on tuber length ($p \leq 0.01$). Furthermore, the interaction effects were significant for both tuber diameter and tuber length, indicating that genotype performance varies depending on the location.

These findings emphasize the importance both genotypes and environmental conditions in determining plant growth and tuber characteristics, thus underscoring the necessity for context-specific recommendations to optimize output.

Table 2. Combined Analysis of variance (ANOVA) for agro-morphological traits and quality related traits of 15 potato genotypes evaluated at Maichew and Ayba in 2016 E.C

Source of variation	**DF**	Mean Squares														
		PH	D50%F	DM	TD	TL	MTNO	UNMTNO	TTNO	ATW	MTY	UNMTY	TTY	TDMC	SG	TSC
Genotype	14	762.76**	228.329**	179.73**	136.997**	465.7716**	50.342**	10.589*	86.64**	1044.4**	309.16**	3.315*	339.74**	150.902**	0.014491**	574.3**
Location	1	13088.72**	3534.400**	2788.90**	15.459ns	361.9627**	1025.629**	0.011ns	1032.26**	160.0ns	4181.92**	8.142*	4559.11**	53.684**	0.011245ns	445.6ns
Replication	2	49.76	8.933	72.71	42.286	15.3501	7.680	3.182	20.72	586.0	120.70	0.924	110.97	9.366	0.006587	261.0
Genotype* location	14	558.12**	21.233*	41.61ns	43.039**	244.4483**	18.140*	3.198ns	27.47*	805.4**	111.60*	2.193ns	122.57**	18.302**	0.002903ns	115.0ns
Error(b)	58	33.49	9.267	25.09	5.137	0.5959	8.159	4.705	13.47	286.4	40.07	1.549	39.29	3.094	0.004350	172.4

*DF= degree of freedom; PH= plant height; D50%F=days to 50% flowering and DM= days to 90% physiological maturity; MTNO= marketable tuber number; UNMTNO =unmarketable tuber number; TTNO=total tuber number; ATW= average tuber weight; MTY=marketable tuber yield; UNMT= unmarketable tuber yield TTY= total tuber yield; TDMC= tuber dry matter content; SG=specific gravity; TSC= tuber starch content. **= Significant at 1% probability level; *= Significant at 5% probability level; ns=non-significant.*

4.2. Performances of genotypes for phenology and growth traits

The ANOVA results indicated a significant genotype × location interaction for plant height (PH) and days to flowering (DF), suggesting that genotypes exhibited varying responses to the environmental conditions at Maichew and Ayba for these traits. Conversely, days to physiological maturity (DM) showed no significant interaction, suggesting that this trait remains relatively stable across both locations (Table 2).

Plant height

The interaction effect of genotype and location revealed a highly significant effect ($p<0.01$) on plant height (Table 2). The tallest genotypes were from the variety burka measuring (110.67 cm), closely followed by G9 (CIP392657.171) (109.4 cm), variety gudene (109.13 cm) and G5 CIP396279.48 (102 cm) all grown at Maichew. These genotypes were significantly taller than the other genotypes. In contrast, the shortest genotypes were G13 (CIP312920.599) (47.67 cm) and G9 CIP392657.171 (48 cm) both grown at Ayba followed by G4 (CIP312921.05) (48.2 cm) grown at Maichew. These shorter genotypes were significantly different from the highest performing genotypes (Table 3).

Branch number

The main effect of genotype had a significant main effect ($P<0.05$) on the average number of branches per hill, whereas location did not. Furthermore, the interaction between genotype and location did not significantly influence this trait. Genotype G2 (CIP312923.637) exhibited the highest average number of branches (14.7), followed by G9 (CIP392657.171) (11.3). In contrast, genotype G6 (CIP312920.528) showed the lowest average branch number (4.1), closely followed by G4 (CIP312921.05) (4.4) (Table 5).

Days to 50% flowering

The analysis of variance indicated that the interaction effect between genotypes and location significantly influenced the days to 50% flowering ($p<0.05$). Specifically, three genotypes G5 (CIP396279.48), variety Burka, and G2 (CIP312923.637) grown at Maichew, demonstrated shorter durations to reach 50% flowering, taking only 45, 46, and 46.67 days, respectively. Conversely, potato genotypes G12 (CIP302498.72), G8 (CIP314030.2), and G4 (CIP312921.05), cultivated at Ayba, required longer periods to attain 50% flowering, taking 75.67, 75.67, and 75 days, respectively (Table 3).

Days to 90% maturity

The ANOVA result reveal that the main effect of genotype and location significantly ($P < 0.01$) influenced days to 90% maturity. However, genotype and location did not interact to influence significant difference on this parameter, where G12 (CIP302498.72) was the earliest genotype, and matured at 90 days. Variety burka took longest days (111.3 days) to attain 90% maturity (Table 5).

Table 3. Interaction effect of genotype and location on growth & phenology traits evaluated at Maichew & Ayba in 2016 E.C

Genotypes	Traits			
	PH		DF	
	Maichw	Ayba	Maichw	Ayba
1. CIP30299.2	62.67^{fgh}	50.47^{i}	57.33^{efgh}	71.67^{kl}
2. CIP312923.637	88.13^{b}	48.33^{i}	46.67^{abc}	55.67^{defgh}
3. CIP397029.21	77.73^{cd}	57.90^{ghi}	51.33^{cd}	68.00^{jk}
4. CIP312921.05	48.20^{i}	49.80i	67.33^{jk}	75.00^{l}
5. CIP396279.48	102.00^{a}	57.40^{ghi}	45.00^{a}	56.00^{defgh}
6. CIP312920.528	71.27^{def}	63.07^{fg}	59.67^{fghi}	72.00^{kl}
7. CIP312921.525	85.53^{bc}	72.00^{def}	54.67^{defg}	58.33^{efgh}
8. CIP314030.2	62.13^{fgh}	51.93^{hi}	60.33^{ghi}	75.67^{l}
9. CIP392657.171	109.40^{a}	48.00^{i}	54.00^{def}	64.33^{ij}
10. CIP393371.164	75.73^{cde}	63.13^{fg}	55.00^{defg}	66.67^{jk}
11. CIP312927.523	85.73^{bc}	62.05^{fgh}	53.33^{de}	69.33^{jk}
12. CIP302498.72	66.67^{efg}	63.53^{fg}	58.33^{efgh}	75.67^{l}
13. CIP312920.599	66.73^{efg}	47.67^{i}	56.67^{defgh}	71.67^{kl}
14. Burka	110.67^{a}	57.00^{ghi}	46.00^{ab}	61.00^{hi}
15. Gudene	109.13^{a}	67.67^{defg}	51.33^{bcd}	64.00^{ij}
Grand mean	69.39		60.73	
LSD (5%)	9.458		4.975	
CV	8.3		5	

Means with the same letter (s) along columns across both locations are not significantly different at P< 0.05; PH= plant height; DF=days to 50% flowering.

4.3. Performances of genotypes for yield and yield component traits

The ANOVA table for yield and yield-related traits of potato genotypes evaluated at Maichew and Ayba highlighted significant variation among genotypes and locations. Genotype differences (treatments) were highly significant ($p<0.01$) for traits like marketable tuber number (MTNO), total tuber number (TTNO), average tuber weight (ATW), marketable tuber yield (MTY), and total tuber yield (TTY), indicating substantial genetic variability affecting yield potential. Genotype × location interaction was significant for traits like total tuber number (TTNO), marketable tuber yield (MTY), total tuber yield (TTY) tuber diameter (TD) and tuber length (TL), suggesting genotype performance varied across locations

Marketable and total tuber number/hill

The interaction effect of genotype and location revealed a significant ($p<0.05$) effect on number of marketable and total tuber number/hill whereas the interaction effect of genotype and location for unmarketable tuber number/hill was not significant. (Table 2).

The genotypes revealed variations for marketable tuber number per hill that ranged from 4.1 to 20.93 and. The highest marketable tuber number per hill (20.93) was obtained from genotype 3 (CIP397029.21) followed by genotype 12 (CIP302498.72) (19.73) and genotype 11 CIP (312927.523) (18.27) grown at Maichew, while the lowest marketable tuber number/hill (4.1) was obtained from genotype 6 (CIP312920.528), G4 (CIP312921.05) (4.27) and G5 (CIP396279.48) (4.67) grown at Ayba respectively (Table 4).

From the tested 15 genotypes total tuber number per hill also ranged from 4.82 to 26.47. Genotype 3 (CIP397029.21) (26.47) and genotype 10 (CIP393371.164) (24.43) grown at

Maichew gave the highest total tuber number while the lowest total tuber number per gill was obtained from genotype 13 (CIP312920.599) (4.82) grown at Ayba (Table 4).

Average tuber weight (g)

The interaction effect of genotype and location showed highly significant differences ($p<0.01$) on average tuber weight (Table 2). Genotype 12 (CIP302498.72) grown at Ayba gave the highest average tuber weight (112.26 g) followed by variety burka grown at Maichew (106.37 g). The lowest average tuber weight (46.73 g) was obtained from genotype 13 (CIP312920.599) grown at Ayba (Table 4).

Tuber diameter (mm)

The interaction effect of genotype and location revealed a highly significant effect ($p<0.01$) on tuber diameter (Table 2). The highest tuber diameter was obtained from G10 (CIP393371.164) (69.89 mm) followed by G2 (CIP312923.637) (67 mm) both grown at Ayba. The lowest tuber diameter was obtained from G13 (CIP312920.599) (48.79 mm) at Maichew (Table 4).

Tuber length (mm)

The interaction effect of genotype and location showed highly significant differences ($p<0.01$) on tuber length (Table 2). The highest tuber length was obtained from G2 (CIP312923.637) (107.18 mm & 106.9 mm) at Ayba and Maichew respectively. The lowest tuber diameter was from 13 (CIP312920.599) (69.9 mm) grown at Maichew (Table 4).

Marketable tuber yield (t ha^{-1})

The interaction effect of genotype and location revealed a significant effect ($p<0.05$) on marketable tuber yield t ha^{-1} (Table 2). The highest marketable tuber yields were obtained from

G12 (CIP302498.72) (46.72 t ha^{-1}), G2 (CIP312923.637) (46.65 t ha^{-1}) and G3 (CIP397029.21) (46.5 t ha^{-1}) grown at Maichew, while the lowest marketable tuber yield was obtained from G13 (CIP312920.599) (12.43 t ha^{-1}) at Maichew (Table 4).

Unmarketable tuber yield (t ha^{-1})

The analysis of variance revealed that the main effect of genotype and location had significant influence ($P<0.05$) on unmarketable tuber yield, whereas the interaction between genotype and location did not significantly influence this trait. The highest unmarketable tuber yield was recorded from Genotype G10 (CIP393371.164) (3.37 t ha^{-1}) whereas the lowest unmarketable tuber yield was recorded from G5 (CIP396279.48) (0.381 t ha^{-1}) (Table 5).

Total tuber yield (t ha^{-1})

The interaction effect of genotype and location revealed a highly significant effect ($p<0.01$) on total tuber yield (Table 2). The highest total tuber yield was recorded from G12 (CIP302498.72) (48.94 t ha^{-1}), G3 (CIP397029.21) (48.71 t ha^{-1}) & G2 CIP312923.637 (48.49 t ha^{-1}) grown at Maichew. The lowest total tuber yield was recorded from G13 (CIP312920.599) (14.27 t ha^{-1}) grown at Ayba. Genotype 12 (CIP302498.72) performed best at Maichew (48.94 t ha^{-1}), whereas it showed moderate performance at Ayba (27.04 t ha^{-1}). Genotype 4 (CIP312921.05) displayed consistent low yields across both locations (16.18 and 16.86 t ha^{-1}) (Table 4).

Table 4. Interaction effect of genotype and location for yield & yield related traits evaluated at Maichew and Ayba in 2016 E.C

	MTNO		TTNO		ATW (g/tuber)	
Genotypes	Maichew	Ayba	Maichew	Ayba	Maichew	Ayba
1. CIP30299.2	15.92^{abcd}	7.27ijklmn	17.79^{bc}	8.80fghij	65.78^{defgh}	56.88^{efgh}
2.CIP312923.637	12.67defghi	11.20defghij	14.20bcdefg	13.80^{cdefg}	90.40^{abcde}	101.00^{abc}
3. CIP397029.21	20.93^{a}	12.20d^{efghij}	26.47^{a}	17.20^{bcd}	56.45^{fgh}	84.32abcdef
4. CIP312921.05	8.47hijklmn	4.27^{mn}	10.40defghij	6.13^{hij}	63.04^{defgh}	95.15^{abcd}
5. CIP396279.48	8.00hijklmn	4.671^{mn}	8.93^{fghij}	5.87ij	77.95bcdefgh	49.57^{gh}
6.CIP312920.528	9.93efghijkl	4.10^{n}	11.87cdefghij	4.82^{j}	94.77^{abcd}	71.60^{cdefgh}
7.CIP312921.525	14.67^{bcdef}	10.33^{fghijk}	15.93^{bcdef}	13.27cdefgh	86.42abcdef	95.81^{abcd}
8. CIP314030.2	16.20^{abcd}	7.60ijklmn	17.73^{bc}	9.73efghij	70.24cdefgh	70.24cdefgh
9.CIP392657.171	14.07^{cdefg}	9.07ghijklmn	15.93^{bcdef}	12.65cdefghi	79.39abcdefgh	62.93^{defgh}
10.CIP393371.164	16.72^{abcd}	7.60ijklmn	24.43^{a}	11.03cdefghj	54.77^{fgh}	99.95^{abc}
11.CIP312927.523	18.27^{abc}	9.73fghijklm	21.13^{ab}	13.12cdefgh	74.35bcdefgh	64.59^{defgh}
12. CIP302498.72	19.73^{ab}	5.47^{klmn}	21.20^{ab}	7.00^{ghij}	81.78abcdefg	112.26^{a}
13.CIP312920.599	14.20cdefg	4.93^{klmn}	17.60^{bcd}	7.27^{ghij}	62.27^{defgh}	46.73^{h}
14. Burka	15.47^{bcde}	7.00^{jklmn}	16.93^{bcde}	8.80fghij	106.37^{ab}	83.11abcdefg
15. Gudene	14.73^{bcdef}	13.27cdefgh	16.47^{bcde}	15.93^{bcdef}	78.59bcdefgh	87.16^{abcdef}
Grand mean	11.29		13.75		77.5	
LSD (5%)	4.668		5.999		27.661	
CV	25.3		26.7		21.8	

*Means with the same letter (s) along column across both locations are not significantly different at P< 0.05; MTNO= marketable tuber number; TTNO= total tuber number; ATW= average tuber weight; **=Significant at 1% probability level; *= Significant at 5% probability level; ns= non-significant.*

Table 4. (Continued): Interaction effect of genotype and location for yield, yield related & quality traits evaluated at Maichew and Ayba in 2016 E.C

Genotypes	Traits									
	TD (mm)		TL (mm)		MTY (t ha^{-1})		TTY (t ha^{-1})		TDMC (%)	
	Maichew	Ayba	Maichew	Ayba	Maichew	Ayba	Maichew	Ayba	Maichew	Ayba
1. CIP30299.2	54.65^{klm}	59.15^{ghij}	91.64^{ef}	83.71^{i}	30.65^{bcde}	17.91^{fghi}	31.38^{cdef}	18.27^{ghij}	26.21^{bcd}	20.46^{ghi}
2.CIP312923.637	65.93^{abcd}	67.00^{ab}	106.90^{a}	107.18^{a}	46.65^{a}	27.43$_{bcdefg}$	48.49^{a}	28.48^{defgh}	20.56^{fghi}	23.66^{def}
3. CIP397029.21	66.08^{abcd}	63.81^{bcdef}	85.76^{h}	80.35^{k}	46.50^{a}	22.48$_{defghi}$	48.71^{a}	24.25$_{efghij}$	28.83^{ab}	28.72^{ab}
4. CIP312921.05	53.92^{klm}	64.22^{bcde}	71.85^{no}	79.32^{k}	15.76^{ghi}	14.79^{hi}	16.86^{ghij}	16.18^{hij}	19.41^{hij}	13.14 ^{m}
5. CIP396279.48	60.75^{efghi}	52.78^{lm}n	75.92^{m}	71.42^{op}	19.02^{efghi}	16.61^{fghi}	19.42^{fghij}	16.98^{ghij}	24.56^{de}	24.76^{de}
6.CIP312920.528	57.95^{hijk}	55.96^{jkl}	83.31^{i}	71.55^{o}	32.43^{bcd}	18.82^{efghi}	34.27^{bcde}	20.79^{fghij}	30.37^{a}	25.25^{cde}
7.CIP312921.525	51.25^{mn}	54.22^{klm}	88.77^{g}	94.62^{d}	31.61^{bcd}	23.70$_{defghi}$	33.82^{bcde}	24.86^{efghij}	18.38^{ijkl}	18.38^{ijkl}
8. CIP314030.2	56.96^{ijkl}	56.91^{ijkl}	101.21^{b}	80.41^{k}	44.80^{a}	22.33$_{defghi}$	47.38^{a}	23.53^{efghij}	15.64^{lm}	15.57^{lm}
9.CIP392657.171	62.34^{cdefg}	59.86^{fghij}	81.83^{j}	77.90^{l}	28.80^{bcdef}	17.00^{fghi}	28.82^{defg}	17.85^{ghij}	22.31^{efgh}	16.80^{jkl}
10.CIP393371.164	4.18^{bcde}	69.89^{a}	101.11^{b}	91.07^{f}	39.31^{ab}	22.18^{defghi}	44.86^{ab}	23.38$_{efghij}$	23.32^{defg}	18.57^{ijkl}
11.CIP312927.523	56.70^{ijkl}	57.11^{ijkl}	88.35^{g}	72.97^{n}	32.87$_{bcd}$	19.28^{efghi}	34.34^{bcde}	20.37^{fghij}	18.39^{ijkl}	23.98^{de}
12. CIP302498.72	61.8^{defgh}	54.05^{klm}	98.29^{c}	76.19^{m}	46.72^{a}	25.83$_{cdefgh}$	48.94^{a}	27.04$_{defghi}$	17.08^{jkl}	13.44^{m}
13.CIP312920.599	48.79^{n}	57.21^{ijk}	69.90^{q}	92.71^{e}	12.43^{i}	15.93^{ghi}	14.27^{j}	17.32^{ghij}	16.32^{jklm}	15.98^{klm}
14. Burka	66.32^{abc}	63.12$_{bcdefg}$	88.03^{g}	77.011^{m}	39.46^{ab}	14.10^{hi}	41.31^{abc}	15.26^{ij}	29.25^{ab}	28.92^{ab}
15. Gudene	51.31^{mn}	56.06^{jkl}	70.17^{pq}	86.48^{h}	37.76^{abc}	21.87$_{defghi}$	38.49^{abcd}	23.26$_{efghij}$	28.23^{abc}	28.67^{ab}
Grand mean	59.01		84.864		26.83		28.31		21.86	
LSD (5%)	3.704		1.2616		10.346		10.245		2.875	
CV	3.8		0.9		23.6		22.1		8	

*Means with the same letter (s) along column across both locations are not significantly different at P< 0.05; TD= Tuber diameter; TL =tuber length; MTY= marketable tuber yield; TTY= total tuber yield; TDMC= tuber dry matter content **= Significant at 1% probability level; *= Significant at 5% probability level; ns= non-significant.*

4.4. Performances of genotypes for tuber quality related traits

The analysis of variance for tuber quality related traits showed that the interaction effect of genotype and location for the tuber dry matter content revealed highly significant (<0.01) effect, but not for specific gravity and tuber starch content. However, the main effect genotype had highly significant (p<0.01) effect on tuber dry matter content and specific gravity, whereas the main effect of location and interaction effect of genotype and location for those traits were non-significant.

Tuber dry matter content (%)

Analysis of variance showed that the interaction effect of genotype and location had highly significant (p<0.01) effect on tuber dry matter content. G6 (CIP312920.528) and variety burka at Maichew had the highest tuber dry matter content of (30.37 and 29.25) respectively. However, genotype 6 (CIP312920.528) was lower dry matter content (25.25) at Ayba. From the tested genotypes, the lowest tuber dry matter content was obtained from G12 (CIP397029.21) (13.14) and G4 (CIP312921.05) (13.44) both grown at Ayba.

Specific gravity

Analysis of variance revealed that specific gravity was highly significantly (P < 0.01) influenced by the main effect of genotype but not by that of location. This parameter was also not significantly influenced by the interaction effect of genotype and location. The highest specific gravity was recorded from variety burka (1.24) followed by G3 (CIP397029.21) (1.19) and variety Gudene (1.18) while the lowest values were observed from genotypes 12 (CIP302498.72) (1.07) and G8 (CIP314030.2) (1.076).

Tuber Starch content (%)

The analysis of variance indicates that the main effect of genotypes had highly significant (<0.01) effect on tuber starch percentage. The highest starch content percentage was obtained from variety burka (45.65), whereas the lowest tuber starch content was obtained from G12 (CIP302498.72) (11.78).

Table 5. Main effect of genotype for yield, yield related traits & tuber quality traits evaluated at Maichew and Ayba in 2016 E.C

Genotypes	Parameters					
	DM	BNO	UNMTNO	UNMTY	SG	TSC
1. CIP30299.2	105.3^{abc}	5.433^{bcd}	1.700^{c}	0.548^{a}	1.118^{bc}	21.43^{bc}
2. CIP312923.637	101.5^{bcd}	14.700^{a}	2.067^{c}	1.446^{b}	1.116^{bc}	20.90^{bc}
3. CIP397029.21	107.2^{ab}	7.533^{bcd}	5.267^{ab}	1.993^{ab}	1.195^{ab}	36.70^{ab}
4. CIP312921.05	101.3^{bcd}	4.467^{cd}	1.900^{c}	1.247^{b}	1.083^{c}	14.33^{c}
5. CIP396279.48	105.5^{abc}	10.600^{abc}	1.067^{c}	0.381^{b}	1.120^{bc}	21.77^{bc}
6. CIP312920.528	99.0^{cde}	4.192^{d}	1.325^{c}	1.903^{ab}	1.120^{bc}	21.77^{bc}
7. CIP312921.525	103.3^{bc}	8.892^{abcd}	2.100^{c}	1.689^{b}	1.088^{c}	15.40^{c}
8. CIP314030.2	94.5^{ef}	6.633^{bcd}	1.833^{c}	1.893^{ab}	1.076^{c}	13.11^{c}
9. CIP392657.171	103.3^{bc}	11.317^{ab}	2.725^{bc}	0.444^{b}	1.091^{c}	16.03^{c}
10. CIP393371.164	104.0^{bc}	6.300^{bcd}	5.572^{a}	3.374^{a}	1.148b^{c}	27.41^{bc}
11. CIP312927.523	99.7^{cde}	7.850^{bcd}	3.125^{abc}	1.280^{b}	1.136b^{c}	25.05^{bc}
12. CIP302498.72	90.0^{f}	6.367^{bcd}	1.500^{c}	1.708^{b}	1.070^{c}	11.78^{c}
13. CIP312920.599	96.0^{def}	5.042^{bcd}	2.867^{abc}	1.618^{b}	1.079^{c}	13.60^{c}
14. Burka	111.3^{a}	10.667^{abc}	1.633^{c}	1.503^{b}	1.240^{a}	45.65^{a}
15. Gudene	106.8^{ab}	9.300^{abcd}	2.200^{c}	1.062^{b}	1.180^{ab}	33.71^{ab}
LSD (0.05)	5.789	5.311	2.507	1.438	0.076	15.174

*Means with the same letter (s) along column across both locations are not significantly different at P< 0.05; DM= days to 90% maturity; BNO =branch number; UNTNO=unmarketable tuber number; UNMTY=unmarketable tuber yield; SG=specific gravity; TSC=total starch content **=Significant at 1% probability level; *= Significant at 5% probability level; ns= non-significant.*

4.5. Correlations among yield and yield components of potato genotypes

According to the analysis indicated in Table 6, total tuber yield showed medium correlation with plant height (r=0.43**), strong correlation with marketable tuber yield (r=0.99**), weak correlation with unmarketable tuber number per hill (r=0.34**), medium correlation with marketable tuber number per hill (r=0.68**) and total tuber number per hill (r=0.58**), whereas negatively correlated with days to 90% maturity (r = -0.47**).

Marketable tuber number per hill had positive and medium correlation with plant height (r=0.44**), weak correlation with unmarketable tuber number (r=0.23*) and strong correlation with total tuber number (0.93**). It had also negative correlation with days to 90% maturity (-0.36**) (Table 8).

Marketable tuber yield (t ha^{-1}) also showed medium correlation with plant height (r=0.45**), marketable tuber number per hill (r=0.68**), total tuber number per hill (r=0.56**), weak correlation with unmarketable tuber yield (r=0.23*) and shows a strong correlation with total tuber yield (r=0.99**). Whereas negatively correlated with days to 90% maturity (r= -0.46**).

Tuber dry matter content percentage showed a weak correlation with plant height (r=0.34**), medium correlation with specific gravity (r=0.45**), tuber starch content percentage (r=0.45**) and weak correlation with days to 90% physiological maturity (r=0.27*).

Tuber starch content percentage was also strongly correlated specific gravity (r=1.00**), moderately correlated with tuber dry matter content (r=0.45**) and weak correlation with plant height (r=0.29*).

Table 6. Correlations among tuber yield and its agronomic traits

	PH	BNO	TTY	MTY	UNMTY	MTNO	UMTNO	TTNO	DM	SG	TDMC	TSC
PH	1											
BNO	0.27*	1										
TTY	0.43**	0.07	1									
MTY	0.45**	0.08	0.99**	1								
UNMTY	-0.01	-0.05	0.34**	0.23*	1							
MTNO	0.44**	0.13	0.68**	0.68**	0.21*	1						
UMTNO	-0.04	0.003	0.00	-0.03ns	0.4**	0.23*	1					
TTNO	0.35**	0.11	0.58**	0.56**	0.33**	0.93**	0.56**	1				
DM	-0.18	-0.03	-0.47**	-0.46**	-0.26*	-0.36**	0.06ns	-0.28*	1			
SG	0.02	0.02	-0.05	-0.06ns	0.001ns	-0.02ns	0.05ns	0.00ns	0.29*	1		
TDMC	0.34**	0.13	0.15ns	0.16ns	-0.01ns	0.17ns	0.09ns	0.18ns	0.27*	0.45**	1	
TSC	0.02	0.02	-0.05ns	-0.06ns	0.001ns	-0.02ns	0.05ns	0.00ns	0.29*	1.00**	0.45**	1

Note: *PH= plant height; BNO=branch number; DM= days to maturity; MTY= marketable tuber yield; UNMTY=unmarketable tuber yield TTY= total tuber yield; MTNO= marketable tuber number; TTNO= total tuber number; TDMC= tuber dry matter content; SG=specific gravity; TSC= tuber starch content.*

4.6. Genetic divergence of genotypes

4.6.1. Principal component analysis

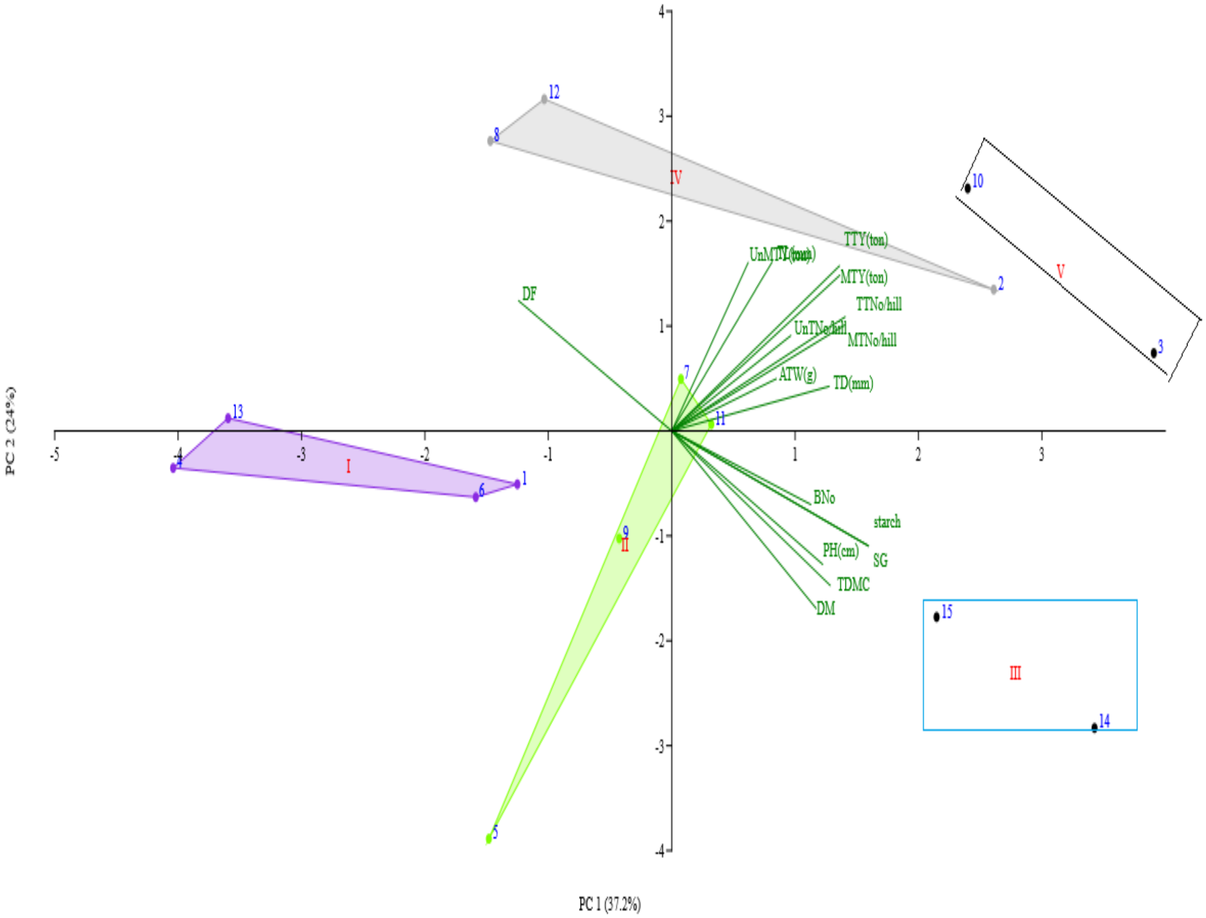
The Table 7, summarizes the results of a principal component analysis (PCA), highlighting the eigenvalues and the percentage of variance explained by each principal component (PC). The first principal component (PC1) explains the largest proportion of variability in the dataset, accounting for 37.161% of the total variance, followed by PC2 with 23.956%, and PC3 with 13.974%. Together, these three components capture 75.091% of the total variance, indicating that they encompass most of the critical information in the dataset. The remaining components, PC4 and PC5, explain smaller portions of the variance (8.073% and 7.02%, respectively), contributing less to the overall structure of the data. Only the first 5 principal components with Eigenvalue > 1 have been presented, as they account for the majority of the total variance (Kaiser Criterion).

Table 7. Eigenvalues and the percentage of variance explained (PCA summary statistics)

PC	Eigenvalue	%variance	Commutative %
1	5.94432	37.152	37.15
2	3.83745	23.984	61.14
3	2.2375	13.984	75.12
4	1.29284	8.0803	83.20
5	1.12211	7.0132	90.21

The provided biplot visualizes the relationships between genotypes (blue points) and traits (green vectors) based on the first two principal components (PC1 and PC2), which explain 37.161% and 23.956% of the total variance, respectively. The distribution of genotypes along these axes indicates their variation and similarity. For instance, genotypes such as G10, G2, and G3 are positively associated with traits that load heavily on the positive side of PC1, while G4 and G13 align more strongly with negative PC1 values, suggesting contrasting traits. The green vectors represent the traits, with the direction and length of each vector indicating the trait's contribution and influence. Genotypes such as G10 and G2 are closely associated with traits located in the positive PC1 and PC2 quadrants. The clustering of certain genotypes, like G12 and G8, suggests similarity based on the traits, whereas others, such as G5 and G15, are more distinct, potentially indicating unique characteristics.

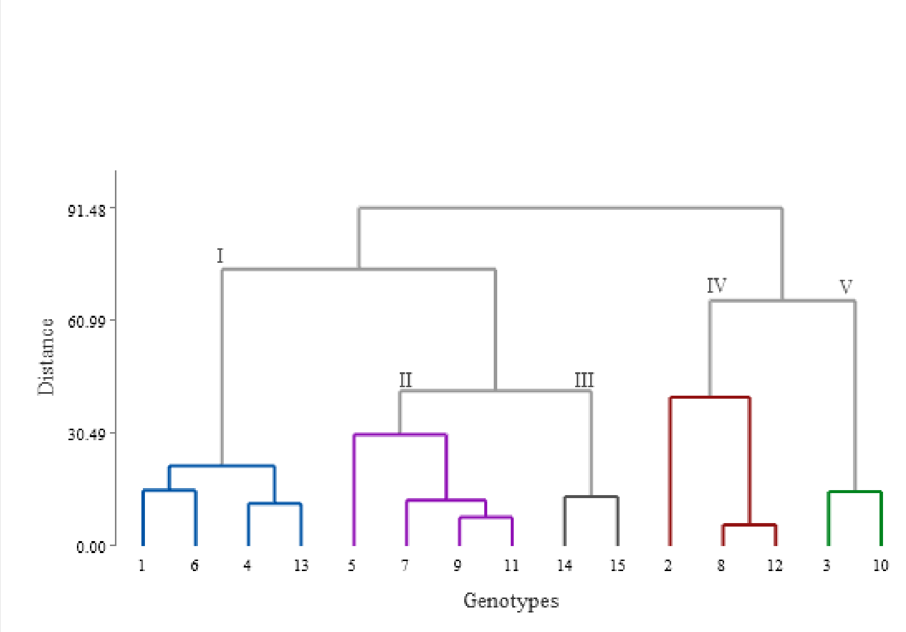
Figure 2. Principal component analysis the genotype-trait relationships



4.6.2. Clustering of genotypes

Dendrogram in figure 2 represents the hierarchical clustering of genotypes (G1 to G15) based on Ward’s linkage and Euclidean distance. The distribution of 15 potato genotype was grouped into five (5) distinct clusters each representing a set of genotypes with higher within-cluster similarity and distinct differences from other clusters. Cluster I includes G1, G6, G4, and G13, which are closely related, suggesting they share common traits or characteristics. Cluster II consists of G5, G7, G9 and G11 distinct from Cluster I but still relatively similar to the genotypes in Cluster III. Cluster III includes G14 and G15 forming a separate group with unique traits that set them apart from the others. Cluster IV contains G2, G8, and G12, which are more closely related to one another than to other genotypes in the dendrogram. Cluster V comprises G3 and G10, which are the most distinct group based on the observed traits. The dendrogram illustrates the genetic diversity or phenotypic variation among the genotypes, with higher vertical distances indicating greater dissimilarity. Clusters can help in targeted breeding, selection programs, or studying genotype responses based on specific traits.

Figure 3. Hierarchical Cluster of Genotypes Using Ward's Linkage and Euclidean distance



4.6.3. Cluster mean analysis

The mean values of five clusters across 16 yield and yield related traits of 15 potato genotypes are listed below in Table 8. The cluster mean values revealed considerable differences among the clusters for different characters.

The highest plant height was recorded from genotypes included in cluster III (86.12 cm) while the lower plant height was measured from genotypes grouped in cluster I (57.48 cm). Genotypes grouped in cluster I take the highest (66.42) days to attain 50% flowering while genotypes in Cluster III take minimum (55.58) days to 50% flowering. Genotypes in Cluster III require maximum (109.08) days to maturity and genotypes in Cluster IV require minimum (95.33) days to maturity. The maximum branch number per hill was obtained from genotypes grouped in Cluster III (9.98 branches) and the minimum branch number per hill was obtained in Cluster I (4.78).

The maximum marketable tuber number per hill (14.36) was obtained from genotype grouped in Cluster V, while the minimum marketable tuber number per hill (8.64) was obtained from genotypes in Cluster I. The maximum unmarketable tuber number per hill (5.42) was obtained from genotypes in Cluster V, while the minimum unmarketable tuber number per hill (1.80) was obtained in genotypes included in Cluster IV. Genotypes in Cluster V (19.78 tubers/hill) gave maximum total tuber number per hill while, genotypes in Cluster I (10.58 tubers/hill) minimum total tuber number per hill.

Genotypes grouped in Cluster IV gave higher marketable tuber yield (35.63 t ha^{-1}), while, genotypes grouped in Cluster I (19.84 t ha^{-1}) had lower marketable tuber yield. The higher total tuber yield per hectare was obtained from genotypes grouped in cluster IV (37.31 t ha^{-1}) followed by cluster V (35.30 t ha^{-1}) while the lower total tuber yield per hectare was obtained from genotypes included in Cluster I (21.17 t ha^{-1}).

Higher tuber dry matter content was measured from genotypes grouped in Cluster III (28.77%), and lower tuber dry matter percentage was measured from genotypes grouped in Cluster IV (17.66%). Maximum specific gravity was recorded from genotypes grouped in Cluster III (1.21) and minimum specific gravity was recorded from genotypes group in Cluster IV (1.09).

Genotypes grouped in cluster III had higher tuber starch percentage (39.68%) followed by cluster II (34.22) while genotypes grouped in cluster IV (15.26%) gave lower tuber starch percentage.

Table 8. Mean values of five clusters for 16 characters in 15 potato genotypes

Cluster	PH(cm)	DF	DM	BNO	TD(mm)	TL(mm)	MTNo/hill	UnTNo/hill	TTNo/hill	MTY(ton)	UnMTY(ton)	TTY(ton)	TDMC	ATW(g)	SG	starch
I	57.48	66.42	100.42	4.78	56.48	80.50	8.64	1.95	10.58	19.84	1.33	21.17	20.89	69.53	1.10	17.78
II	77.76	56.88	102.96	9.66	56.88	81.47	11.10	2.25	13.35	23.61	0.95	24.56	21.02	73.88	1.11	19.56
III	86.12	55.58	109.08	9.98	59.20	80.42	12.62	1.92	14.53	28.30	1.28	29.58	28.77	88.81	1.21	39.68
IV	63.46	62.06	95.33	9.23	60.45	95.03	12.14	1.80	13.94	35.63	1.68	37.31	17.66	87.87	1.09	15.26
V	68.63	60.25	105.58	6.92	65.99	89.57	14.36	5.42	19.78	32.62	2.68	35.30	24.86	73.87	1.17	32.05

Note: *PH= plant height; BNO=branch number DF=days to 50% flowering; DM= days to 90% physiological maturity; MTY=marketable tuber yield; UNMT= unmarketable tuber yield TTY= total tuber yield; TD= Tuber diameter; TL =tuber length; TDMC=tuber dry matter content; SG= specific gravity; TSC= tuber starch content.*

4.6.4. Estimation of cluster distance

Results in table 9. Represents the Euclidean distances between the centroids (central points) of five identified clusters in a multivariate space. The result indicated the presence of considerable distances or dissimilarities among the studied genotypes. These distances indicate the degree of separation or dissimilarity between the clusters. A higher distance implies that the clusters are more distinct from each other, while a smaller distance suggests greater similarity.

Cluster 1 is closest to Cluster 4 (distance = 3.4103), indicating these two clusters are more similar compared to others. Cluster 3 is most distant from Cluster 4 (distance = 6.72734), suggesting significant differences between them. Cluster 2 has moderate distances from all other clusters, with the smallest distance to Cluster 1 (3.67166) and the largest to Cluster 4 (6.22684). Cluster 5 shows relatively uniform distances to the other clusters, but it is closest to Cluster 4 (4.44024).

Table 9. Distances Between Cluster Centroids

	Cluster1	Cluster2	Cluster3	Cluster4	Cluster5
Cluster 1	0	3.67166	5.31926	3.4103	4.36814
Cluster 2	3.67166	0	4.46546	6.22684	5.78626
Cluster 3	5.31926	4.46546	0	6.72734	5.95928
Cluster 4	3.4103	6.22684	6.72734	0	4.44024
Cluster 5	4.36814	5.78626	5.95928	4.44024	0

CHAPTER FIVE: DISCUSSION

The significant variation observed among potato genotypes across different traits highlights the rich genetic diversity, likely stemming from the diverse parental lines used in developing these varieties. The presence of significant genotype-by-environment (G × E) interactions and strong environmental influences for most traits confirms that genotype performance was affected by varying environmental conditions. However, for traits such as days to 90% maturity, specific gravity, and tuber dry matter content, the lack of significant genotype-by-location interaction suggests stable performance across locations. In contrast, significant genotype-by-location interactions for other traits imply differential responses of genotypes to location-specific environmental factors.

5.1. Phenology and growth characteristics of genotypes

The observed differences in plant height among the genotypes of the current study may be attributed to genetic makeup and interaction effect of genotypes by environment (GxE). This finding aligns with Bilate and Mulualem, (2016) who also reported substantial effects of cultivar and their interaction on plant height in Eastern Ethiopia. (Abebe Chindi et al., 2021) reported that Gudanie had the tallest plants (74.87 cm), followed by Belete (72.86 cm) and CIP-396034.103 (72.40 cm), while CIP-391046.14 was the shortest (61.48 cm). (Ebrahim et al., 2018) observed a plant height range from 65.70 to 122.70 cm, along with variation in stem number and leaf area index. According to Singh and Singh (1973), plant height is a polygenic trait highly influenced by environmental variables such as nutrients, moisture and light.

The differences in days to 50% flowering among genotypes are attributed to genetic variability and adaptability to environmental conditions. Awoke Ali, (2020) observed flowering durations ranging from 45 to 53 days across 36 genotypes, with differences influenced by genotype, temperature, light, and adaptability. Similarly, the variation in days to 90% maturity can be explained by genotype and environmental interactions. (Tsagaye et al.,2023) found maturity durations ranging from 103 to 113.33 days, while Awoke Ali,(2020) reported ranges between 86 and 106 days, showing the impact of genetic diversity, planting date, climate, and agronomic practices.

5.2. Yield performance and yield Components

The wide variability in marketable and total tuber yield among the currently studied potato genotypes could be due to the genetic differences among the genotypes and genotype by environment interaction. The differences among genotypes and locations might be due to potential adaptability of varieties to different locations. Similar tuber yield variation results were reported on potato by different scholars in Ethiopia. (Habtamu et. al., 2016) also reported that the variation in total tuber yield of potato genotypes at the study areas may be due to a response of the genotypes to growing environmental factors. In addition, he also stated that yield differences among genotypes were attributed both by the inherent yield potential of genotypes and growing environment as well as the interaction of genotype x environment. (Abebe chindi et al.,2021) studied 10 potato genotypes had displayed a wide range of variation in total tuber yield that ranged from 25.41 to 39.89 t ha-1 with the mean performance of 31.46 t ha-^{1}. (Degebasa et al., 2016) and Bilate and Mulualem, (2016) further emphasized the role of genotype-environment interactions.

The variation in tuber diameter is due to genotype and the interaction effect of genotype by environment. The result of the present study indicates that interaction between genotype and location is highly significant, for tuber diameter indicating the impact of genotypes on tuber diameter differs between the two locations. For instance, G10 gave the highest tuber diameter at Ayba (69.89 mm), but at Maichew G10 gave lower average (64.18 mm). This suggests that some genotypes perform better in one location over another. This is in agreement with study of Assefa Nigatu, (2023) who reported that the genotypes revealed variations for tuber diameter that ranged from and 3.08 to 4.68 cm^2.

Differences in unmarketable yield likely resulted from genotypic adaptability and genetic predispositions to tuber defects. Elfinesh, (2008) also reported significant effects of genotype on unmarketable yield. Average tuber weight variation is linked to genotype, especially differences in tuber bulking rate and duration, which are further influenced by environmental conditions. (Habtamu et al.,2016) and Zerihun, (2016) reported significant effects from genotype, location, and their interactions. (Eaton et al.,2017) attributed weight differences to genetic potential, seed quality, agro-ecology, and crop management.

Genotypic differences, and G × E interactions also affected total and marketable yields. These yield variations suggest that specific genotypes are better adapted to certain locations. Some genotypes, like G2 and G3, showed much greater yield potential at Maichew compared to Ayba, indicating genotype-by-environment interactions. Tuber number and size, key components of yield, determine market value and farmer adoption. (Gebreselassie et al., 2016) noted that Belete produced the highest marketable yield in Eastern Ethiopia. Abebe Chindi, (2020) emphasized genotypic efficiency in utilizing resources as a yield determinant, while Lemma et al., (2020) also found significant yield differences among genotypes. Several Ethiopian studies including those by (Habtamu et al., 2016), (Abebe Chindi et al., 2021), (Getachew et al., 2016), and (Ebrahim et al., 2018) consistently report wide yield variability among genotypes, ranging from 0.8 to 46.1 t ha^{-1} with average yields between 19.4 and 31.63 t ha^{-1}. Rangare and Rangare, (2017) similarly observed significant yield differences among genotypes.

5.3. Tuber quality attributes

Tuber dry matter content was significantly influenced by environmental conditions. Wassu, (2016) found that Belete consistently had the highest dry matter content across multiple seasons and sites. Bilate and Mulualem, (2016) and Getachew et al., (2016) also confirmed significant environmental, varietal, and interaction effects. Getachew et al., (2016) reported dry matter content range of 7.6% to 30.5% among 24 genotypes. Specific gravity variation was largely genetic. (Damtew et al., 2022) and Bilate and Mulualem, (2016) found significant varietal effects on specific gravity, with minimal genotype-by-location interaction. Belete showed the highest values at Adea Berga (1.109) and Holetta (1.094). (Chindi et al., 2021) emphasized that specific gravity, highly correlated with dry matter content, directly influences processing quality. Higher specific gravity results in better processing yield, reduced oil absorption, and improved texture. Additionally, lower sugar content enhances appearance and flavor by minimizing darkening. (Rukundo et al., 2019) also highlighted the importance of genotype, location, and season on potato growth, yield, and quality traits, underscoring the value of multi-environment evaluations in breeding programs.

In the present study, high specific gravity and dry matter value were obtained from late matured cultivars like Burka followed by Gudene. (Iwama et al., 1975) reported that increasing the growing period of potato increased the dry mass of the leaves, stems and roots. This is in agreement with the findings of Burton, (1966) who reported that the dry matter content of early maturing cultivars is usually lower than that of the later maturing varieties.

5.4. Correlations among yield and yield components

The relationship between yield and agronomic traits is important to the plant breeders to find out the traits correlated with yield and also how they are associated among themselves. The result of the present investigation showed that total tuber yield t ha^{-1} showed positive and highly significant correlation with plant height, marketable tuber yield, unmarketable tuber number per hill, marketable tuber number per hill, and total tuber number per hill. Similar findings were also observed by Berhan, (2017) who obtained significant correlation between tuber yield with stem per plant, tuber number per plant, average tuber weight and tuber weight per plant, marketable tuber yield and non-marketable tuber yield. This suggests that an increase in positively associated traits helps enhance yield. Therefore, improvement of tuber yield in potato is possible by using appropriate breeding strategy through selection for those positively correlated traits. Similarly, positive and significant correlation between marketable tuber yields with total tuber yield was reported by (Panigrahi et al., 2017) average tuber weight with total tuber yield has been reported by Rahman, (2015), (Sattar et al., 2007).

(Amadi et al., 2008) also reported that a significant positive correlation between tuber yield with number of tubers per plant (r = 0.49) and days to maturity (r = 0.15) at phenotypic level. This indicated that as those traits increases with increasing the total tuber yield which implies that improving those correlated traits can simultaneously improve tuber yield of the studied genotypes. Similar finding was reported by Kelilachew (2021), a correlation coefficient of +1.00 tells that there is a perfect positive relationship between the two variables. This means that as the values of one variable increase there is a predictable increase in values of the other variables.

This means those traits had the chance to selection of potato for breeding, it contributes with improvement of tuber yield. Similar findings (Ortiz et al., 2021) reported there were significant correlations ($p \leq 0.05$) between the characteristics may suggest that there is an opportunity for trying indirect selection for the characteristic with the largest heritability to maximize genetic gains.

5.5. Genetic divergence of genotypes

5.5.1. Clustering genotypes

The dendrogram presented in Figure 2 illustrates the hierarchical clustering of fifteen potato genotypes (G1–G15), constructed using Ward's linkage method and Euclidean distance. The analysis effectively grouped the genotypes into five distinct clusters, each characterized by a high degree of intra-cluster similarity and inter-cluster dissimilarity. This clustering structure reflects the underlying genetic and phenotypic diversity among the studied genotypes and offers valuable insight for breeding and selection programs. Cluster I, comprising G1, G6, G4, and G13, exhibits a close genetic relationship, suggesting these genotypes may share similar agronomic or morphological characteristics. Such tightly associated genotypes are ideal for consolidating favorable traits and could serve as elite parental lines in breeding efforts. Cluster II, including G5, G7, G9, and G11, forms a group that is moderately related to Cluster III, which consists of G14 and G15. The separation of Cluster III indicates that these two genotypes possess distinct attributes potentially valuable for introducing novel traits into the breeding gene pool. In contrast, Cluster IV (G2, G8, and G12) demonstrates a unique grouping of genotypes that are more related to each other than to those in other clusters, pointing to a shared genetic background. Notably, Cluster V, made up of G3 and G10, stands out as the most divergent, suggesting that these genotypes harbor the most unique or extreme traits among the group valuable for broadening the genetic base.

The overall clustering pattern confirms the presence of significant genetic variation, which is critical for maintaining a dynamic breeding pool. This observation is consistent with findings from previous studies. For instance, (Tesema et al., 2020) applied hierarchical clustering to Ethiopian potato genotypes and reported similar grouping patterns based on agronomic performance. Likewise, (Girma et al., 2017) identified distinct clusters among southern Ethiopian cultivars, highlighting cluster analysis as an effective tool in identifying genotypes with high tuber yield and disease resistance. (Gebru et al., 2017) conducted a multivariate analysis on Ethiopian potato genotypes and highlighted clustering as a robust approach to guide genotype selection.

Additionally, (Singh et al., 2014) confirmed the effectiveness of hierarchical clustering in distinguishing Indian potato cultivars using a combination of morphological and biochemical traits. Taken together, these studies validate the present findings and emphasize the importance of cluster analysis in genotype characterization. The five clusters identified in this study offer a strategic foundation for breeding programs aiming to improve specific traits, enhance adaptability, or develop novel cultivars. Furthermore, recognizing genetically distant genotypes, such as those in Cluster V, allows for the introduction of new alleles and minimizes genetic redundancy within breeding pools. In sum, the hierarchical clustering pattern revealed in this study highlights the rich genetic diversity among the 15 potato genotypes. The distinct groupings provide practical guidance for targeted breeding, germplasm conservation, and the development of superior cultivars. Maintaining such diversity is crucial not only for current crop improvement efforts but also for ensuring long-term agricultural resilience and food security.

5.5.2. Principal component analysis

Principal component analysis (PCA) was computed to find out the characters, which accounted more to the total variation. This suggests that dimensionality reduction can be effectively achieved by retaining only the first three PCs, simplifying the dataset while preserving the majority of its variability. These components can then be used for further analysis, such as clustering or visualization, to identify patterns and groupings within the data. A study by Ali Awoke (2020) reported that from the total of 18 principal components extracted, the first six PC‟s with an Eigen value >1 accounted for 78.22% of the total variation and the first, second and third PC‟s with an eigenvalue (5.4, 2.8 and 2.2) accounted (30.06%, 45.58% and 57.88%) of the total variability among the studied 36 potato genotypes respectively. Seid et al. (2021) also reported that the first eight principal components accounted for 90.26% of the total variation among 24 potato genotypes for the 23 quantitative and six qualitative traits. Of these, the first, the second and the third principal components constituted 28.69%, 18.74% and 13.00% of the variation, respectively. Ghebreslassie et al., (2017) also studied 21 potato genotypes, reported that components with an eigenvalue of 1 or higher were significant.

5.5.3. Cluster mean analysis

According to the cluster mean analysis of characters, developing varieties for tuber yield through selection and further evaluation of genotypes from Cluster IV and V is possible to obtain genotypes with highest total tuber yield. Rangare and Rangare, (2017) reported that potato genotypes clusters constructed and that had higher mean values for desirable traits including tuber yield and quality traits. (Ebrahim et al., 2017) also reported the grouping of 36 potato genotypes into eight cluster that had highest total tuber yield, specific gravity of tuber, dry mater content, total starch content, acceptable tuber physical and frying quality and other desirable traits.

CHAPTER SIX: CONCLUSION AND RECOMMENDATION

6.1. Conclusions

In conclusion, the study identified significant variability among the tested potato genotypes concerning traits of economic importance, emphasizing the potential for selecting genotypes with high tuber yield and yield-related traits. The results demonstrate that different genotypes possess varying genetic potential across locations. Among the 15 tested potato genotypes, the highest total tuber yields were obtained from G12 CIP302498.72 (48.94 t ha^{-1}), G3 (CIP397029.21) (48.71 t ha^{-1}), and G2 (CIP312923.637) (48.49 t ha^{-1}), G8 (CIP314030.2) (47.38 t ha^{-1}), G10 (CIP393371.164) (44.86 t ha^{-1}), variety burka (41.31 t ha^{-1}) and variety Gudene (38.49 t ha^{-1}) all grown at Maichew. Conversely, the lowest total tuber yield was obtained from G13 CIP312920.599 (14.27 t ha^{-1}) grown at Maichew.

The interaction analysis also revealed that potato genotypes G12 (CIP302498.72), G3 (CIP397029.21), and G2 (CIP312923.637), grown at Maichew, produced higher total and marketable tuber yields within the irrigation production system. These introduced potato genotypes outperformed nationally released varieties in terms of marketable tuber yield, total tuber yield, and other related agronomic traits under both Maichew and Ayba conditions.

Total tuber yield (t ha^{-1}) exhibited positive correlations with several traits: plant height ($r = 0.43$), marketable tuber yield ($r = 0.99$), unmarketable tuber number per hill ($r = 0.34$), marketable tuber number per hill (r = 0.68), and total tuber number per hill (r = 0.58). A negative and highly significant correlation was observed between total tuber yield and days to maturity (r = -0.47).

Overall, this study highlights the diverse genetic variability present among the potato genotypes examined for most of traits. This information, along with the identified genotypes and their associated traits, will be valuable for future potato breeding programs in the country.

6.2. Recommendations

Among the tested varieties, genotypes G12 (CIP302498.72), G3 (CIP397029.21), and G2 (CIP312923.637), G8 (CIP314030.2), G10 (CIP393371.164), variety burka and variety gudene are recommended for their superior tuber yield at Maichew. Additionally, genotypes G2 (CIP312923.637), G12 (CIP302498.72), G7 (CIP312921.525), G10 (CIP393371.164) and variety gudene are also recommended for the specific conditions at Ayba. Disseminating these genotypes to local farmers is essential for improving potato production and productivity in areas utilizing an irrigation production system.

However, it is important to note that this research was conducted over one season at two locations. Therefore, further studies are needed across multiple seasons and locations to better understand the specific variability among genotypes, as well as the impact of late blight and other relevant quality parameters in the southern zone of Tigray and similar agroecological regions.

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8. Appendix

Table 1: List of the experimental materials included in the study

N<u>o</u>	Genotypes	Genotype Code	Source	Remarks
1	CIP30299.2	G1	HARC	Accession
2	CIP312923.637	G2	HARC	Accession
3	CIP397029.21	G3	HARC	Accession
4	CIP312921.05	G4	HARC	Accession
5	CIP396279.48	G5	HARC	Accession
6	CIP312920.528	G6	HARC	Accession
7	CIP312921.525	G7	HARC	Accession
8	CIP314030.2	G8	HARC	Accession
9	CIP392657.171	G9	HARC	Accession
10	CIP393371.164	G10	HARC	Accession
11	CIP312927.523	G11	HARC	Accession
12	CIP302498.72	G12	HARC	Accession
13	CIP312920.599	G13	HARC	Accession
14	Burka	G14	HARC	Released variety
15	Gudene	G15	HARC	Released variety

Appendix figure 1: during field lay out and furrow making

Field layout & furrow making at Maichew

Appendix figure 2: during planting

Planting at Maichew

Planting at Maichew

1st and 2nd Earthing up at Maichew

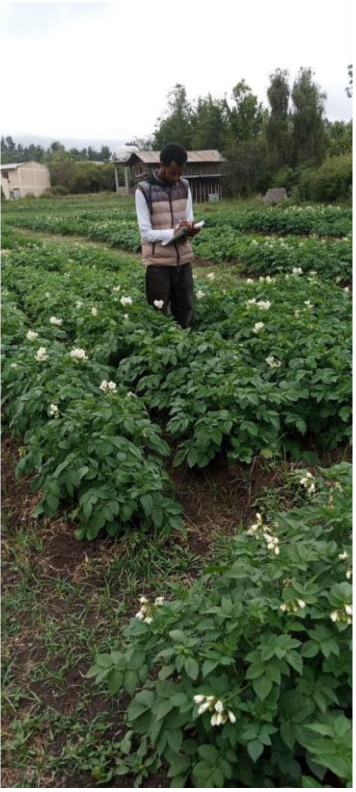
Appendix figure 3: during fungicide spraying

Fungicide spraying at Maichew

Appendix figure 4: during flowering staage

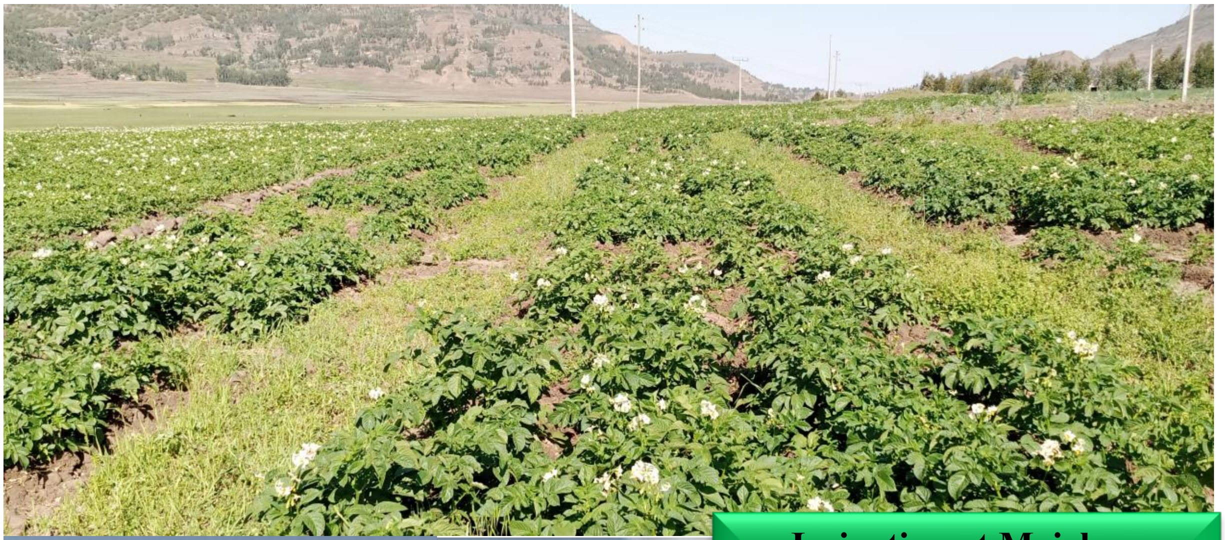
Emba Alaje woreda

When I was taking flowering data at Maichew



When I was taking flowering data at Maichew

at flowering stage (Emba Alaje woreda)



Irrigation at Maichew

Flowering stage at Maichew

Appendix figure 5: Harvesting photos

Harvesting & data collection (at Maichew)

Harvesting & data collection (at Emba Alaje)

Harvesting & data collection (at Emba Alaje)

Appendix figure 6: ovendrying of potato tuber for tuber dry matter content