**VARIABILITY FOR YIELD, YIELD COMPONENTS AND QUALITY OF POTATO (*Solanum tuberosum* L.), CULTIVARS TESTED IN CENTRAL ETHIOPIA**

**MSc THESIS**

**ABDU YASSIN**

**HAWASSA UNIVERSITY**

**COLLEGE OF AGRICULTURE**

**Hawassa, Ethiopia**

**November, 2019**

# Variability for Yield, Yield Components and Quality of Potato (*Solanum tuberosum* L.), Cultivars Tested in Central Ethiopia

**ABDU YASSIN**

**Major Advisor: Hussein Mohammed Ali (PhD)**

**Co-Advisor: Tesfaye Abebe Desta (PhD)**

**A Thesis Submitted to School of Plant and Horticultural Sciences College of Agriculture, Hawassa University**

**Hawassa University**
**College of Agriculture**

**In Partial Fulfillment of the Requirements for the MSc Degree in Plant Sciences (Specialization: Horticulture)**

**Hawassa, Ethiopia**

**November, 2019**

# ADVISORS' APPROVAL SHEET

COLLEGE OF AGRICULTURE

SCHOOL OF PLANT AND HORTICULTURL SCIENCES

(Submission Sheet-1)

This is to certify that the thesis entitled "**Variability for Yield, Yield Components and Quality of Potato (*Solanum tuberosum* L.)Cultivars tested in central Ethiopia"**

**S**ubmitted in partial fulfillment of the requirements for the degree of **Master'** with specialization in **Horticulture** the Graduate program of the **Department/School of Plant and Horticultural Science**, and has been carried out by **Abdu Yassin Mohammed** Id No SGS/Hort/021/09, under my/our supervision. Therefore, I/we recommend that the student has fulfilled the requirements and hence here by submit the thesis to the department.

| | | |
|---|---|---|
| ______________________ | ______________ | ______________ |
| Name of major advisor | Signature | Date |
| ______________________ | ______________ | ______________ |
| Name of co-advisor | Signature | Date |

EXAMINERS' APPROVAL SHEET

School of Graduate Studies
Hawassa University
Examiners' Approval Sheet-1

We, the undersigned members of theBoard Examiners of the Final open defense by **Abdu Yassin**, have read and evaluated his thesis entitled "**Variability for Yield, Yield Components and Quality of Potato (*Solanum tuberosum* L.) Cultivars Tested in Central Ethiopia"** and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirement for the degree of **Master of Science in plant Sciences with Specialization in Horticulture.**

| | | |
|---|---|---|
| -------------------------------- | -------------------------------- | ----------------------- |
| Name of Chairperson | Signature | Date |
| -------------------------------- | -------------------------------- | ----------------------- |
| Name of Major Advisor | Signature | Date |
| ______________________________ | ______________________ | ----------------------- |
| Name of Co-advisor | Signature | Date |
| ----------------------------- | ------------------------- | ---------------------- |
| Name of Internal Examiner | Signature | Date |
| ----------------------------- | ------------------------- | ---------------------- |
| Name of External Examiner | Signature | Date |
| -------------------------------- | ---------------------------- | --------------------- |
| SGS | Signature | Date |

Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the school of Graduate studies (SGS) through the school Graduate committee (SGC) of the candidate's School.

Stamp of SGS Date -------------------------

**N.B**:-use this form to submit the thesis with **minor correction** suggested by the examining board

## DEDICATION

This Work is dedicated to my beloved grandmother, W/ro Hawa Dawud for her love, support and encouragement.

# STATEMENT OF THE AUTHOR

First of all, I declare and affirm that this thesis is the result of my genuine work. I have followed all ethical and technical principles of scientific methods in the preparation, data collection, data analysis and compilation of this Thesis. Any scholarly matter that is included in the Thesis has been given recognition through citation.

I submitted this thesis to Hawassa University in partial fulfillment of the requirements for the award of the Degree of Master of Science. The thesis is deposited at the library of the University to be made available to borrowers for reference. I solemnly declare that the thesis has so far not been submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

Brief quotations from this thesis are allowed without requiring special permission provided that an accurate acknowledgement of the source is made. Requests for extended quotations from or reproduction of this manuscript in whole or part may be granted by the head of the Department of Plant Sciences or by the Dean of the School of Graduate Studies of the University when, in his or her judgment, the proposed use of the material is for a scholarly interest. In all other instances, however, permission must be obtained from the author.

Name: Abdu Yassin Signature: ________________________

Place: Hawassa University, Hawassa

Date of submission: ----------------------

# ACKNOWLEDGEMENTS

First, I would like to give greatest thanks to the Almighty Allah who provided all the required resources, knowledge, strength and wisdom for the fulfillment of this study. I would also like to express my deepest and heartfelt thanks as well as my most sincere appreciation and gratitude to my major research advisor Dr. Hussein Mohammed and to my co-advisor Dr. Tesfaye Abebe for their keen interest, ever readiness to provide assistance, suggestions, advice, consistent guidance, critical review and for giving me comments on the manuscript and throughout the course of this research starting from proposal preparation up to the final thesis write up. Without their help, it was not be possible to complete this study.

I would also like to express my appreciation and thanks to Amhara Regional Agricultural Research Institute (ARARI) for giving me this opportunity and for paying my monthly salary while I was on study leave and covering the research budget. I want to express my gratitude and deepest appreciation to Debre Birhan Agricultural Research Center (DBARC) for its assistance in provision of materials and facilities. Special thanks are extended to Ato Abiy Legesse, Center Manager of DBARC, for his genuine assistance in all activities during the study period. I am obliged to extend my deepest gratitude to Zerihun Kebede, Natnael Girma, Yifru Worku, Kalkidan Yalew, Ashenafi Kebede, Kenzemed Kasse and other members of DBARC for their unreserved assistance for the research work starting from site selection until the end of the experiment.

I would like to thank Bahir Dar University for allowing me to use laboratory facilities in quality analysis and for their technical support during the work. Special thanks are extended to Shimelis Abate, Laboratory technician of Bahirdar University in this regard. I want to thank my wife Kelsum Jemal for shouldering responsibilities of our home during my whole study period and also to my Sons, Semir Abdu and Mohammed Abdu for their patience.

I am obliged to extend my deepest gratitude to Fasikaw Belay, Shimels Abebe, Shambel Besufikad, Aschalew Abebe, Gebre Garmame, Manalegn Emiru and for all my dorm mates for their cooperation and encouragement during my stay on campus and writing this thesis.

# LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ANOVA | Analysis of Variance |
| ARARI | Amhara Regional Agricultural Research Institute |
| AwARC | Awassa Agricultural Research Center |
| CIP | International Potato Center |
| CSA | Central Statistics Agency |
| DBARC | Debre Birhan Agricultural Research Center |
| DMRT | Duncan's Multiple Range Test |
| FAO | Food and Agricultural Organization |
| GCV | Genotypic Coefficient of Variation |
| $H^2$ | Heritability in Broad Sense |
| HARC | Holeta Agricultural Research Center |
| MANR | Ministry of Agriculture and Natural Resources |
| MoARD | Ministry of Agriculture and Rural Development |
| PCV | Phenotypic Coefficient of Variation |
| RCBD | Randomized Complete Block Design |
| ShARC | Sheno Agricultural Research Center |

# TABLE OF CONTENTS

## TABLE OF CONTENTS (continued)

## TABLE OF CONTENTS (continued)

# LIST OF FIGURES

**Figure** **Page**

# LIST OF TABLES

**Table** **Page**

**LIST OF TABLES (Continued)**

# LIST OF TABLES IN THE APPENDIX

***Variability for Yield, Yield Components and Quality of Potato (Solanum tuberosum L.), Cultivars Tested in Central Ethiopia***

Abdu Yassin (BSc in plant Sciences, Haramaya University)

Major Advisor: Hussein Mohammed Ali (PhD)
Co-Advisor: Tesfaye Abebe Desta (PhD)

## *ABSTRACT*

*This experiment was conducted in three replications of the randomized complete block design at Debre Birhan during 2017 main growing season to assess the nature and magnitude of variability in twelve potato cultivars for tuber yield and nutritional quality. There were highly significant differences among twelve cultivars in all characters, except in days to maturity. The highest and lowest total tuber yield was obtained from Bubu (36.86 t $ha^{-1}$) and Dinkey (16.28 ton $ha^{-1}$), respectively. Genotypic and phenotypic coefficient of variation ranged from 0.79 to 88.9% and from 0.84 to 92.43%, respectively. Heritability and genetic advance as percent of mean (GAM) ranged from 65.35% to 97.53% and from 1.63% to 183.52%, respectively. High heritability values were coupled with high GAM for all characters except for plant height, total carotenoids, starch content and tuber dry matter for which heritability and GAM were moderate. These values were low for days to maturity and tuber specific gravity. Most of the traits can successfully be improved through hybridization and selection. Total tuber yield $ha^{-1}$ was positively and significantly correlated with marketable tuber yield, average tuber weight, plant height and starch content but was negatively correlated with iron and crude protein content at both genotypic and phenotypic levels. Maximum positive direct effect on total tuber yield $ha^{-1}$ was exhibited by average tuber weight at genotypic level and by marketable tuber yield $ha^{-1}$ at phenotypic level. Cluster analysis showed that the cultivars were grouped into five clusters. Cluster I was high in average tuber weight and starch content. Cluster-III was high in total carotenoids, crude protein, iron and zinc but low in total tuber yield $ha^{-1}$corroborating the negative correlation between tuber yield and nutritional quality except Zn content. Results of this study demonstrated that there is sufficient genetic variability among the potato cultivars. However, it is difficult to make conclusion with one season and one location experiment. Therefore, it is recommended to evaluate more cultivars over locations and seasons to reach on more valid conclusion.*

***Key words:*** *Cluster analysis, Correlation, Heritability, Path analysis, Potato*

# 1. INTRODUCTION

Potato (Solanum tuberosum L.) belongs to the family Solanaceae. It was first domesticated and also originated in South America, the Andes region of Peru and Bolivia more than 8,000 years ago (Hawkes, 1994). It is now commercially grown in over 125 countries throughout the world from China's Yunnan plateau and the subtropical lowlands of India to Java's equatorial highlands and the steppes of the Ukraine (Sriom *et al*., 2017). It is one of the most important widely grown wholesome food crops in Ethiopia as well as many countries of the world and contributes immensely to human nutrition and food security to the growing global population (Adissu *et al*., 2013). The high yield potential of potato and its plasticity to environmental regimes makes it as one of the best crops in the national food security program and to full fill nutritional requirements in Eastern Africa (Kyamanywa *et al*., 2011), It plays a major role in poverty reduction, income generation and provides employment for many societies in the production, processing and marketing sub-sectors (Lung'aho *et al*., 2007; Ovchinnikova *et al*., 2011). There is some estimate that crop yield should have to double by 2050 to meet the demand of global food. Importantly, potatoes are affordable, putting them within reach of the economically disadvantaged groups of people (Wassu, 2016). According to Fayera (2017), the yield potential of potato is about six to seven times more compared to that of rice and wheat from a unit area and time resulting in about five fold more benefit. It has the ability to provide a high yield per unit area of land and high-quality product per unit input with a shorter crop cycle (mostly < 120 days) than major cereal crops like maize (Adane *et al*., 2010).

Potato is a nutrient dense, low calorie food. It is a good source of carbohydrates, high quality protein and when eaten with the skin contains appreciable amounts of several micronutrients including vitamin C, phosphorous and potassium (Camire *et al*., 2009). It is an excellent low fat source of carbohydrates. Besides being rich source of carbohydrates, potato also contains some health promoting compounds such as phenolic acids, ascorbic acid and carotenoids (Ezekiel *et al.*, 2013; Kumar *et al.,* 2017). It is one of the most important vegetable and starch supplying crop having high production per unit area per unit time. It is rich source of vitamins, especially 'C' and 'B'. Tubers contain 70-80% water, 20.6% carbohydrate, 2.1% protein, 0.3% fat, 1.1% crude fiber and 0.9% ash (Guta, 2017). Carotenoids are referred to as important for the human diet because of several health promoting activities. Most of these have antioxidant properties and are reported to be beneficial in preventing cancer, cardiac and eye diseases (Krinsky *et al*., 2004).

Rich genetic variability (diversity) has been reported in populations of potato in agronomic and nutritional quality traits. Among methods of analyzing genetic diversity the assessment of phenotypic coefficient of variation, genotypic coefficient of variation, genetic advance, genetic advance as percent of mean and heritability are some important tools. The existence of genetic variability among different parameters contributing to yield is an important criterion for yield and quality enhancement. To initiate any breeding program assessing the presence of enough genetic variability in the population for interested characters should be considered as a pre requisite element (Kumar *et al.,* 2017; Rahman *et al*., 2016). Information on the genetic diversity in a population and genetic variability components play a vital role for the success of any crop improvement program. Knowledge of the genetic diversity of a potato population is a useful tool for an efficient choice of parents for hybridization that aimed at developing high yielding cultivars with desirable features (Arslanoglu *et al.,* 2011). Assessing the causes and magnitude of variation is the key to success in any breeding program, as difference will always exist among individuals in a plant population. Selection in breeding programs is based on measurement of phenotypic characters and genotypic variability (Singh, 1990). Studies on genotypic and phenotypic correlations among characters of crop plants are useful in planning, evaluating and setting selection criteria for the desired characters in the breeding program (Johnson *et al.,* 1955). The total observed variation, phenotypic variation, is made up of genetic and environmental component of variations. Genotypic variation, which arises due to the genotypic difference and the base for selection is the main concern of plant breeders. The variability of a trait describes how much that trait tends to vary in response to environmental and genetic influences (Allard, 1960). Potato cultivars are generally distinguished on the basis of morphological traits and have a wide range of variability of botanical characters. Phenotypic characterizations of root and tuber crops are done by assessing variations in the flower, leaf and tuber characteristics (Huaman, 1991).

Several local and improved potato cultivars are cultivated by farmers in the central highlands of Ethiopia. Local cultivars that were introduce before one and half century without formal variety releasing procedures is present at the hands of farmers for quite long periods of time in Ethiopia. Even though released varieties exhibit good tuber characteristics, comprehensive data regarding their quality characteristics need to be evaluated. Not all released cultivars are good for all end uses, hence, intensive varietal evaluation should be conducted to analyze and identify suitable cultivar for a particular use. It is necessary to assess cultivars for their nutritional content to design their best end use. In Ethiopia, different research centers and institutions have released a number of improved potato cultivars. In developing those cultivars much emphasis was given for adaptability, productivity per unit area and late blight resistance. But Selection of potato cultivars should not be limited to high yield, but also for internal and external quality of tubers (Ebrahim *et al*., 2018). Despite the importance and widespread production of potato in this area, few studies that are fragmented were carried related to physicochemical attributes like dry matter content, total soluble solid, starch content, specific gravity, geometric mean diameter and surface area; which are very crucial quality parameters but substantially varying across environments (Asmamaw *et al*., 2010; Elfnesh *et al*., 2011; Habtamu *et al*., 2016a; Tesfaye *et al*., 2012, 2013; Wassu, 2016, 2017). These studies don't also include total carotinoids quality attributes, and iron and zinc content in tubers of the studied cultivars. Hence, sufficient information is not available on the variability in agronomic and nutritional characteristics of available potato cultivars. There is a critical gap of information related to the nature and extent of variability among potato cultivars in agronomic and nutritional traits. The present study was conducted to fill this gap and to investigate the availability of sufficient variability in both agronomic and nutritive traits of potato cultivars under production in central Ethiopia and had the following objectives.

**General Objective**

The overall objective of the current study was to assess the nature and magnitude of variability in potato cultivars for tuber yield and quality.

**Specific Objectives**

1. To study the variability in tuber yield, yield related traits and in quality traits and determine traits that can be easily improved through selection.
2. To determine association among tuber yield on one side and other agronomic and tuber quality traits to identify traits that can be used in indirect selection for higher tuber yield and also suggest a selection strategy for simultaneous improvement of tuber yield and tuber quality.

3. To identify cultivars superior in tuber yield and hence those that can be advanced for further testing and to be used in future improvement work.
4. To identify cultivars with superior quality to be include in further testing and recommended for specific use.

# 2. LITRATURE REVIEW

## 2.1.Taxonomy and morphology of potato

Potato (*Solanum tuberosum* L.) belongs to family*Solanaceae*. It consists of about 90 genera and 3,000–4,000 speciesthe largest of which is the genus *Solanum*, including about 1,500 species. About 100 species of *Solanum* are tuber-bearing, and thus commonly referred to as potato. Besides, a number of species are locally cultivated for their edible fruits, tubers, or leaves, as well as for horticultural purposes (Machida-Hirano, 2015; Spooner, 2009). Taxonomists have experienced difficulty in the ordering of species within the solanum genus. It has been controversial with anywhere up to 20 species recognized (Huaman and Spooner, 2002). The subsection Potatoe contains both cultivated and wild underground stolons bearing potato tubers at their tips, including common potato (*S. tuberosum*, belonging to series *Tuberosa*). Two non-tuber-bearing series (*Etuberosa and Juglandifolia*) are placed in subsection *Estolonifera* (Machida-Hirano, 2015; Ovchinnikova *et al*., 2011). The latest comprehensive taxonomic treatment of section Petota was published by Spooner *et al*., (2014), it recognizes eight cultivated species and 228 wild species, divided into 21 taxonomic series, including 19 series for tuber-bearing species and two series of non-tuberous species. Among these eight cultivated species of section Petota only *S. tuberosum ssp. tuberosum* is grown worldwide others are restricted to the Andean countries where thousands of primitive cultivars are found. Cultivated potato species with their chromosome numbers varying from diploid ($2n = 2x = 24$), triploid ($2n = 3x = 36$), tetraploid ($2n = 4x = 48$), pentaploid ($2n = 5x = 60$) to hexaploid ($2n = 6x = 72$) (Spooner, 2009).

Potato is herbaceous plant that may range from erect to fully prostrate. Plants produce rhizomes (often called stolons) that have rudimentary leaves and are typically hooked at the tip. They originate from the basal stem nodes, typically below ground, with up to three rhizomes per node (Spooner and Knapp 2013; Struik, 1990).Potato tuber is not a storage root, but rather a specialized swollen underground stem of the plant; they too come in a wide variety of colors, shapes and sizes. Tubers, spherical to ovoid in shape, are swellings of the rhizome. The flesh of the tubers varies in color from white to yellow to blue and the skin varies from white through yellow to tan and from red through blue. The color of the flesh may or may not correspond to the color of the skin. On the surface of the tuber are axillary buds with scars of scale leaves that are called eyes (Spooner and Salas 2006; Struik, 1990). If a whole tuber or piece of tuber containing one or more buds or eyes is planted, sprouts arise under certain conditions and a plant develops above the ground (Otroshy, 2006). Tubers are harvested for both food and seed. When tubers are planted, the eyes develop into stems to form the next vegetative generation. The tuber is known to supply carbohydrate, high quality protein, and substantial amounts of essentials vitamins, minerals and trace elements (Horton and Sawyer, 1985).

## 2.2.Origin and distribution of potato

The cultivated potato originated and was first domesticated more than 8,000 years ago in the region near Lake Titicaca, which is located at an elevation of 3,800 m above sea level in the Andes mountain, on the border between extreme north western Bolivia and modern day southern Peru in South America. It thereafter expanded to Mexico and Central America (Hawkes, 1994). Their natural habitats span an immense geographic range from the southwestern United States to central Chile and Argentina, displaying significant variation in temperature, moisture, soil quality and biological stresses (Hijmans and Spooner, 2001; Spooner and Salas, 2006). Adaptation to such a broad assortment of ecological pressures has generated extensive diversity in wild and landrace populations (Spooner and Bamberg, 1994). From South America potato tardily started its travel across the continent, but it acquired great importance in 1530s when Spanish conquistadors searched for gold in Peru. They brought potato to Europe between the years of 1570 and 1593. Subsequently the crop was distributed throughout the world. Irish immigrants took the tuber and coined the name, "Irish potato" to North American crop in the early 1700s. In the 19$^{th}$ century it expanded to Asia. Spanish explorers took it into Africa. In the 20$^{th}$ century, potato became one of the most beloved and produced food sources in the world. United States of America was the last major country which adopted potato. Now potato is cultivated throughout the world in more than 100 countries in Europe, North America and countries of the former Soviet Union, Asia, Africa and Latin America (Beukema and Zaag, 1990; FAOSTAT, 2015). It was introduced to Ethiopia before 160 years ago 1n 1858 by a German Botanist Schimpe (Horton, 1987; Pankhrust, 1964).

### 2.3.Potato production in Ethiopia

Ethiopia has possibly the greatest potential for potato production in Sub-Saharan Africa. Ethiopia is among the ten leading Sub-Saharan Africa countries in terms of area of potato production (FAOSTAT, 2015). About seventy percent of its arable land is mainly in the highland areas which receive an annual rainfall of more than 600 mm, which is suitable for potato cultivation (Gebremedhin *et al*., 2008). However, despite the substantial increase in land allotted to potato production in the country as a secondary non-cereal crop, the national average yield of potato remained one of the lowest in the world and never reached the potential that it has in supporting food security. Potato can potentially be grown on about 70% of the 10 Million ha of arable land in the country (FAO, 2008). There are improved varieties that yield 19–38 Mg $ha^{-1}$ on farmers' fields (Gebremedhin *et al*., 2008). However, in 2015/16 meher (main rainy) season the total potato production area in Ethiopia reached 70,131 ha and its production was 943,233 tones. In Belg 2016 (short rainy) season its area of production was 226,428 ha and its production was 2,691,169.2 tons. All arable lands that are suitable for potato production do not produce potato. Only 2.9 % of the potential area in Ethiopia is under potato production and the national average yield was 13.45 ton $ha^{-1}$ (CSA, 2016 a, b).This is very low compared with other potato growing countries that were reported by Roy *et al*. (2017), New Zealand (47.74 t $ha^{-1}$), Netherlands (45.66 t $ha^{-1}$), USA (47.15 t $ha^{-1}$), Japan (30.65 t $ha^{-1}$), and India (22.92 t $ha^{-1}$).The major production problems that account for such low yield are unavailability of quality seed for varieties that are high yielding as well as adapted to wide range of agro-ecologies of the country, high cost of seed tubers, poor agronomic practices, absence of proper pest and disease management practices, unavailability of proper transport, storage and marketing facilities are the prominent ones (Gildemacher *et al*., 2009; Adane *et al*., 2010).

Potato is one of the few crops in Ethiopia that matures during the months of July and August and thus has an important role in alleviating hunger or/and to ensure adequate food supply during food shortage months and as well as an important source of cash income (Gebremedhin *et al*., 2013). In Ethiopia, the major potato growing areas are located in the central, the eastern, the northwestern and the southern parts of the country. In the central area, potato production includes the highland areas surrounding the capital, Addis Abeba, within a 100–150 km radius. In this area the major potato growing zones are West Shewa and North Shewa. In the central area, farmers grow about seven local varieties, eight improved varieties and six clones (i.e. genetic material which is not officially released) (Adane *et al*., 2010).

Ethiopia is neither the center of origin nor the center of diversity for potato. But the crop has been cultivated for more than 150 years in the country. Hence, a set of local varieties has been developed through a constant process of farmer experimentation, evaluation and selection of introduced varieties or clones from outside sources (Semagn *et al*., 2015). In the absence of sufficient genetic variation or the difficulty of creating variation through crossing in the country, it is necessary to introduce potato genotypes every time from outside sources. The introduced genotypes need to be evaluated for target areas or for wide adaptability across regions in the country (Getachew *et al.* 2016). Here tremendous variation in altitude, temperature, rainfall, soil type, and ecological settings gives rise to the need for a wide range of cultivars, which are not likely to be provided by existing breeding programs (Cavatassi *et al*., 2011).

The Ethiopian potato research system has released 36 new potato varieties to address some of the production problems (MoANR, 2016). From these new varieties limited number is grown in some parts of the country, and also their adoption by farmers in most potato production areas is low. The majority of farmers still grow their own local potato cultivars, so this is one of the causes of insufficient seed quality in the seed potato system in Ethiopia. The low uptake of released cultivars may be related to the high costs of recommended production methods for these varieties (Tesfaye *et al.* 2013; Adane *et al*., 2015).

### 2.4.Nutritional and quality characters of potato

Potato is eaten boiled, roasted, baked or fried and processed into a very wide range of products, such as canned whole potatoes, frozen French fries or chips, crisps, dehydrated flakes, powder or granules, potato salad, etc. (Stark *et al*. 2009). Traditionally, consumers select potatoes by visual characteristics such as tuber size, shape, color and skin brightness in the fresh market. However, there has been an increasingly higher interest on the part of consumers for use of the nutrient-rich potato, because population based epidemiological studies have stressed the important role of diet (especially mineral malnutrition) and lifestyle in the emergence of many degenerative chronic diseases such as cancers and cardiovascular diseases, in both developed and developing countries (Andre *et al*., 2007). Nutritional value of potatoes is determined by the content of nutrients such as protein, starch, fat, minerals, and absence of toxins, as well as by a significant content of bioactive components from the group of polyphenols, which guarantee proper antioxidant activity of this vegetable (Gumul *et al*., 2011). It is one of the main agricultural products where the amount of protein, starch, carbohydrates and essential amino acids, vitamins and minerals are important in human nutrition (Akhavan *et al*., 2007). Potato supply as a raw material for processing industry must fulfill a number of requirements including low sugar contents, high dry matter, more specific gravity, high antioxidants (Vit C), low weight loss, good color and with no sprouting (Amjad *et al*., 2016). Carbohydrates constitute approximately 75% of total dry matter and potatoes are a good source of protein, vitamins, dietary fiber and some minerals. An average (175 g)serving of potato provides over 40% of the Recommended Daily Allowance for vitamin C, approximately 30% of vitamin B6 requirement, 16% of vitamin B1 requirement, 16% of folate requirement and is also an important dietary source of potassium (18%), iron (6%) and magnesium (Storey, 2007).

The physical and chemical characteristics of the potato tubers vary from one variety to another and within the same variety. Physical characteristics of agricultural products are the most important parameters in the design of grading, handling, processing and packaging systems (Habtamu *et al*., 2016a). Consequently, potato varieties with a dry matter content of 20% or higher, a starch content of 13% and above and/ or a specific gravity of 1.08 or higher are the most preferred for processed products (Kirkman, 2007). Andre *et al*., (2007) and Ekin, (2011) were demonstrated the wide variability of health-promoting micronutrient levels within the potato cultivars Tesfaye *et al*., (2013), also evaluated Specific Gravity of Potato for determining the processing quality of potato varieties.

### 2.5.Genetic Variability

The existence of variability in a particular trait and assessing the causes and magnitude of this variation is the key to success in breeding program for its heritable improvement. Particularly, genetic variability for a given character is a basic prerequisite for its improvement by systematic breeding, (Engida *et al*., 2007; Tekola, 2014). Potato is a highly heterozygous out crossing species which is asexually propagated, via tubers, for food production and germplasm maintenance. Sexual propagation and the production of 'true' seed allow breeders to generate genetic variation, and as a clonal crop, there are opportunities to exploit both additive and non-additive variation (Getachew and Tesfaye, 2016). Potato genetic variation vary in ploidy levels (diploid to hexaploids) and show a high degree of diversity in tuber size, shape, skin and flesh colour, and cooking quality (Andre *et al*., 2007).

It was evident that yield and quality cannot be improved simultaneously rather independent selection for both may be beneficial (Datta *et al*., 2014). The presence of wide variations among varieties for tuber specific gravity, dry matter and starch contents indicates that genetic factor is important to influence the tuber internal quality traits (Wassu, 2016). Wide range of variability for yield and associated characters in potato has been reported by Addisu *et al*. (2013), nine potato varieties and four locally available potato varieties genotypic variance took relatively much of the total variances for plant height, big tuber percentage, small tuber percentage per plant and days to flower.

### 2.5.1.Genotypic and phenotypic variability

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 magnitudes differ under different environmental condition. Genotypic variability, on the other hand is the component of variation which is due to the genotypic difference among individuals within a population, and is the main concern of plant breeders (Singh, 2001). Potato cultivar development traditionally uses a phenotypic-based selection strategy (Ebrahim, 2018). Conventionally, plant breeders recombine the desired genes from crop varieties and related species by sexual hybridization and develop new cultivars with the desirable traits such as high yield and resistance to disease, insect and pests and drought (Kromann *et al*., 2014).

However, selection of parents to be used in the crossing program based on known genetic information and breeding value is crucial to increase the probability of success in the improvement program (Ebrahim, 2018). According to Raje and Rao (2000), genetic variability is essential in order to realize response to selection pressure as the estimates of genetic parameters of variation are specific for a particular population and the phenotypic expression of the quantitative character may be altered by environmental stress that affect plant growth and development. Genotypic and phenotypic coefficients of variation are used to measure the variability that exists in a given population (Burton and Devane, 1953). Phenotypic and genotypic coefficients of variation values had been classified as high (>20%), medium (10-20%) and low (<10%). The lower value of PCV generally depicts low; while a high proportion of to the PCV is desirable in breeding works.

Regarding potato, research results have been published on genetic variability that has been done at different locations with genotypes and years. Ebrahim (2018) reported high PCV and GCV value for average tuber number, average tuber weight, unmarketable tuber yield, small size tubers and large size tubers percentage. Bala and Rangare (2017) reported the existence of sufficient amount of variability among genotypes for all the studied characters which indicated that the genotypes were widely variable. Getachew *et al*. (2016) reported that both genotypic and phenotypic coefficients of variation estimates were high for days to flowering, plant height, stem number per hill, marketable tuber number per hill, average tuber weight, marketable tuber yield and total tuber yield. Sattar *et a*l. (2007) reported high genotypic coefficients of variation for number of tubers per plant, yield per plant and average weight of a tuber. Tripura *et al*. (2016) reported high GCV and PCV for average tuber number per plant, average tuber weight and tuber yield per plot. Addisu *et al.* (2013) obtained high PCV and GCV for Plant height, number of stem/plant; tuber yield, tubers number per plant; small tuber percentage and big tuber percentage in potato. Hayes *et al*., (2012) reported significant difference among clones for Fe and Zn and showed that the content of these elements can be improved through breeding. High values of GCV and PCV suggest that there is a possibility of improvement through direct selection for the traits. On the contrary, Tripura *et al*. (2016) reported low PCV and GCV in single tuber weight. Getachew *et al*. (2016) and Sattar *et al*., (2007)also reported that days to maturity had both GCV and PCV lower than 10% that can be considered as low, and hence these traits provide practically less chance for selection.

### 2.5.2.Heritability

Heritability is defined as the measure of the correspondence between breeding values and phenotypic values. Thus, heritability plays a predictive role in breeding, expressing the reliability of phenotype as a guide to its breeding value. It is the breeding value which determines how much of the phenotype would be passed onto the next generation (Tazeen *et al*., 2009). It is very important to plant breeders as it gives an indication of the effectiveness with which selection of accessions could be executed based on phenotypic performance of quantitative characters (Allard, 1960). There are two types of heritability: broad and narrow sense heritability. Heritability in the broad sense is the sum of additive, dominance and epistatic effects (Falconer and Mackay, 1996). The use of estimates of heritability and genetic variances gives further chances of improvement of potato populations by selection. Potato is a clonally propagated crop, the genotypic content of parents and their offspring are identical; therefore, heritability estimators in the broad sense should be used to predict the response to selection within a breeding population. This genetic variability is utilized in selection between asexual generations (Tai and Young, 1984; Nyquist, 1991). Heritability estimates along with genetic gain are considered to be more useful in predicting the outcome of selecting the best individuals.

However, it may be noted that heritability value indicates the relative effectiveness of selection based on phenotypic expression of a character but, genetic advance is more useful in predicting the actual value of selection (Johnson *et al.* 1955). Getachew *et al*. (2016) reported high heritability for marketable tuber yield, total tuber yield, average tuber weight and tuber dry matter content. Kumar*et al*. (2017) reported high heritability of dry matter %, total tuber yield and marketable tuber yield for two harvesting days. Addisu *et al*. (2013) also reported high broad sense heritability estimates for tuber diameter (96%), days to 50% flowering (50%) and plant height (50%). Mishra *et al*. (2006) reported high heritability estimates for plant height, tuber dry matter content, specific gravity of tubers and tuber yield per plant.

### 2.5.3.Genetic advance

Genetic advance is the measure of the expected genetic progress that would result from selecting the best performing genotypes for a character being evaluated. It measures the difference between genotypic values of generation obtained from the selected population over the mean value of the base population (Allard, 1960). It is also a selection parameter of considerable importance that aids breeders in a selection program because it indicates the magnitude of the expected genetic gain from one cycle of selection (Hamdi*et al*., 2003). It is achieved through selection and its success depends on the factors of total variation in the population in which selection is conducted (Acquaah, 2007). High genetic advance with high heritability estimates offer the most effective condition for selection (Larik *et al*., 2000). Mishra *et al.* (2006) concluded that high heritability and high genetic advance would be valuable in selection programs. Haydar *et al*. (2009) reported high estimates of heritability and genetic gain for plant height, number of branches, tuber number and yield indicating that these traits are largely controlled by additive gene action and that selection for them would be effective. Tripura *et al*. (2016) reported high heritability in broad sense coupled with genetic advance for tuber yield, tubers plant$^{-1}$, plant height, and tuber weight per plant.

## 2.6.Correlation and Path Coefficient Analysis

### 2.6.1.Correlation coefficient analysis

Correlations between different characters of crop plants may arise either from genotypic or environmental factors. Characters that are not easily measured or which are largely influenced by the environment have low heritability and hence, there is a need to examine the relationships among various characters (Burhan, 2007). It is necessary to have a good knowledge of those characters that have significant association with yield because these characters can be used as indirect selection criteria or indices to enhance performances of varieties in a new plant population (Lemma, 2018). Direct selection for yield and yield is not effective as it is a complex quantitative character and it is highly influenced by environment. Thus effective improvement in yield may be brought about through selection on yield component characters. Therefore, the correlation between yield and yield components are of considerable importance in selection programs. Correlation studies between yield and their relative contribution to yield have surplus value in planning a breeding program. The aim of correlation studies is primarily to know the suitability of various characters for indirect selection because selection on any particular trait may bring about desirable or undesirable changes in other associated characters (Singh, 1998).

The existence of strong positive correlation between potato tuber yield and different traits helps in identifying traits that could be used for indirect selection of higher yielding cultivars. The intensity and direction of association of the different traits with yield were estimated with genotypic and phenotypic coefficient of correlation (Mode and Robinson, 1959). Higher genotypic correlation than phenotypic correlation indicated an inherent association between various characters (Johnson *et al.,* 1955). A significant association suggests that such characters could be improved simultaneously (Tripura *et al*., 2016). Getachew and Wassu (2016), observed positive and significant genotypic correlations between total tuber yield per hectare and marketable tuber yield, plant height, stem number per plant, average tuber weight and marketable tuber number per hill. Tripura *et al*. (2016) observed that tuber yield was positively and significantly correlated with tuber number per plot at genotypic as well as phenotypic levels. Tuber number was found to have positive and significant association with total tuber yield. Kumar*et al*. (2017) observed significant positive correlations between total tuber yield and marketable and non-marketable tuber yield suggesting that selection for these two traits would give good response for total tuber yield. Sattar *et al*., (2007) also reported highly significant genotypic and phenotypic correlation between number of tubers per plant and weight of tubers per plant.

### 2.6.2.Path coefficient analysis

Path coefficient analysis is used as an effective tool in finding out the direct and indirect effects of different contributing characters towards yield. Each component possesses a large direct effect on yield and its important indirect effects via different yield components (Fonseca and Patterson, 1968). Path coefficient analysis is used as an effective tool in finding out the direct and indirect effects of different contributing characters towards yield. In most studies involving path analysis, researchers considered the predictor characters as first-order variables to analyze their effects on a dependent or response variable such as yield (Ntawurunga *et al*., 2001). Getachew and Wassu (2016) reported that marketable tuber yield, average tuber weight, stem number per plant and marketable tuber number per hill had positive direct effect at genotypic and phenotypic level on total tuber yield. Abraham *et al.* (2014) and Sattar *et al*. (2007) observed that plant height and average tuber weight had positive direct effect on tuber yield. Ebrahim (2018) reported that days to maturity, average tuber weight, marketable tuber yield, unmarketable tuber yield, large size tubers, geometric mean diameter, specific gravity of tubers and dry matter content exerted positive direct effect on total tuber yield $ha^{-1}$. Hayder *et al*. (2009) and Mondal (2003) also reported strongest positive direct positive effect of effect of plant height on tuber weight per plant.

# 3. MATERIAL AND METHODS

## 3.1.Description of the study area

The experiment was conducted under rain fed condition during the 2017 main cropping season at Debre Birhan Agricultural Research Center (DBARC) experimental testing site of Faji, which is located in Basona Werana woreda, North Shewa zone, Amhara Regional State, central Ethiopia. Debre Brihan is located 130 km north east of Addis Ababa. The geographical coordinates of the specific research site (Faji) is 09º 36' 18" north latitude and 39º 29' 45" east longitude with the elevation of 2850 m.a.s.l. (Haymanot *et al*., 2015). Climatic records of Debre Birhan Agricultural research meteorology station for thirty three years (1985 to 2015) show that the mean annual rainfall at Debre Birihan is 934.17 mm. It has unimodal rainfall pattern (July to September) that has a maximum of 293.07 mm in July and minimum of 4.67 mm in December (Appendix Tables 1 and 4). The mean annual maximum temperature is 19.82$^{o}$C and monthly values ranged between 18.4 $^{o}$C in August and 21.8 $^{o}$C in June (Appendix Tables 3 and 4). The mean annual minimum temperature is 6.4 $^{o}$C and monthly values range between 2.8 $^{o}$C in November and 8.8 $^{o}$C in June.The coldest month is November while the hottest months are June and May (Appendix Table 2 and 4). The area is demarcated by three seasons, locally known as Bega, the dry season (October to January), Belg the short rainy season (February to May) and Kiremt, the long rainy season (June to September). The soil type is vertisol with clay loam texture and slightly acidic (Haymanot *et al*., 2015).

## 3.2.Experimental Materials and Design

### 3.2.1.Experimental materials

The Experiment was conducted using eight improved potato varieties (Alemaya-624, Awash, Menagesha, Gorebella, Gera, Shenkolla, Belete and Bubu) which were released by regional and national research institutions at different times (Table 1). We tried to select and arrange varieties based on releasing year, from the first variety (Alemaya-624) that was released from Haramaya university in 1987 to Bubu that was released in 2011 at the same University to get variation and included four farmers' cultivars (Keydinich, Enat beguaro, Akime, and Dinkey) collected from farmers' fields. Then, in 2016 all planting materials were multiplied in DBARC and kept in diffused light stores to ensure healthy sprouts and proper stand of crop.

Table 1: Description of released and local cultivars (treatments)

| No | Varieties | Year of Release | Breeder/ Maintainer | Recommended Altitude (m.a.s.l) | Type of material |
|---|---|---|---|---|---|
| 1. | Alemaya 624 | 1987 | HU | 1500-2500 | variety |
| 2. | Awash | 1991 | HARC/EIAR | | variety |
| 3. | Menagesha | 1993 | HARC/EIAR | | variety |
| 4. | Gorebella | 2002 | ShARC/ARARI | 2700-3200 | variety |
| 5. | Gera | 2003 | ShARC/ARARI | 2700-3200 | variety |
| 6. | Shenkolla | 2005 | AwARC | 1700-2700 | variety |
| 7. | Belete | 2009 | HARC/EIAR | 1600-2800 | variety |
| 8. | Bubu | 2011 | HU | 1650-2330 | variety |
| 9. | Keydinich | Local Cultivar | | | Local |
| 10. | Enatbeguaro | Local Cultivar | | | Local |
| 11. | Akime | Local Cultivar | | | Local |
| 12. | Dinkey | Local Cultivar | | | Local |

Source: - (MoANR, 2016)

HU=Haramaya University; HARC= Holeta Agricultural Research Center; AwARC= Awassa Agricultural research center; EIAR=Ethiopian Institue of Agricultural Research;

### 3.2.2.Experimental design

The experiment was conducted during the main growing season of 2017 (June-December). It was arranged in randomized complete block design (RCBD) with three replications and each plot was 3 m x 3 m (= 9 $m^2$) consisting of four rows each 3m long and accommodating 10 plants. A total of 40 plants were planted per plot. Planting was conducted on June 18 at a spacing of 75 cm between rows and 30 cm between plants. The spacing between plots and between adjacent replications (blocks) was 1 m and 1.5 m, respectively. Tubers were harvested from plants in the two middle rows (3.6 $m^2$); by leaving the plants in the two border rows as well as one plant at both ends of each row to avoid border effects.

## 3.3.Experimental Procedures

The experimental fields were plowed two times by tractor and leveled by hoe. Ridges were made by hand. Medium sized and well sprouted tubers were planted on June 18, 2017 during the main growing season. A total of 46 kg N, 92 kg $P_2O_5$ and 17 kg Sulphur $ha^{-1}$ (242 kg $ha^{-1}$ of NPS) was applied at planting in the form of blended fertilizer NPS (19% of Nitrogen, 38% of $P_2O_5$ and 7% of Sulphur) as a substitute for the past recommendation of 200 kg $ha^{-1}$of DAP (Diammonium Phosphate).Additional Nitrogen was applied at the rate of 100 kg $ha^{-1}$Urea (46% N) in three splits (1/4$^{th}$ at planting, 1/2 at mid-stage of growth or 45 days after planting, and 1/4$^{th}$ at tuber initiation or at the start of flowering). Earthing up was done twice: the first just before the last top dressing of urea that was 45 days after planting and the second at flower initiation stage. Weeds were controlled by uprooting manually. Dehaulming of the crop was done two weeks before harvesting manually to thicken tuber periderm (skin); as the plants reached physiological maturity (yellowing or senescence observed apparent on the lower leaves) which helped to avoid bruising and skinning during the harvesting and post-harvest handling (Habtamu *et al*., 2016b).

## 3.4.Data collection

Pre and post-harvest data were collected on phenological and growth parameters, on tuber yield and yield components and on tuber quality attributes. Data for growth parameters were collected from five randomly selected plants from the net plot area of each plot, on all plants in each net plot for crop phenology, while five kg tubers were taken from each net plot for specific gravity and four hundred gram tuber was randomly taken from each net plot for dry mater content. Data on yield and yield related traits were taken from 16 plants in the net plot. The description of data recording and measurements for each trait are given below under each category of traits.

### 3.4.1.Phenology and growth parameters

**Days to 50% emergence:** The number of days from planting to the emergence of 50% of plants in each plot.

**Days to 50% flowering**: - This was recorded as the number of days taken from planting to the days when 50% of plants in the central two rows produce flowers.

**Days to maturity (DM)**:- It was recorded by counting number of days from planting to days on which more than 90% of the plants in each plot attained physiological maturity. Genotypes with maturity date ≤ 90 days are designated as early maturing, those that mature in 90 to 120 days are designated as medium maturing and those maturing in more than 120 days are designated as late maturing (Muhinyuza *et al*., 2014).

**Plant height (cm):** The height of five randomly selected plants from the ground surface to the tip of the main stem measured in centimeter and averaged to get the mean plant height in cm.

### 3.4.2. Tuber yield and yield components

These data were taken from 16 plants randomly sampled from the two central rows.

**Marketable tuber yield (t $ha^{-1}$)**: This was determined from the weight of tubers obtained from the net plot from tubers which are free from attack by diseases and insect pests and from tubers greater than or equal to 20 g in weight. This was converted to ton $ha^{-1}$(Habtamu *et al*., 2016b).

**Marketable tuber number $ha^{-1}$:-** This was determined from the number of tubers obtained from the net plot from tubers which are free from attack by diseases and insect pests and from tubers greater than or equal to 20 g in weight (Habtamu *et al*., 2016b). This number was then converted to number of marketable tubers $ha^{-1}$.

**Unmarketable tuber yield (t $ha^{-1}$)**: The average weight of tubers that are diseased, insect attacked and small-sized (< 20 g) from the net plot area was converted to ton per hectare.

**Unmarketable tuber number $ha^{-1}$:-**it was determined as the number of unmarketable tubers from the net plot area; tubers which were rotten, green, cracked, insect attacked and undersized (less than 20 g). This was then converted to number of unmarketable tubers $ha^{-1}$.

**Total tuber yield (t $ha^{-1}$)**: It was determined as the sum of marketable and unmarketable tubers weight from the net plot area and converted to ton $ha^{-1}$.

**Total tuber number $ha^{-1}$:** This was calculated by counting all the tubers harvested from the net plot area and converted to total number of tubers $ha^{-1}$. It is the sum of unmarketable and marketable tuber number $ha^{-1}$.

**Average tuber weight (in gram)**: This was determined by dividing the total fresh tuber yield from the net plot area to their respective total tuber number.

**Average tuber number per hill:** Recorded at harvest as the actual number of tubers collected from all experimental plants in each net plot divided by the number of plants from net plot.

**Tuber size distribution (%):** All tubers harvested from the net plot area were categorized into three groups (small, medium and large). Small tubers are those weighing <39g, medium tubers are those whose weight is between 39 and75g, while large tubers are those whose weight is greater than 75g (Lung'aho *et al*., 2007). The proportion of number of tubers in the different tuber size categories was converted to percentages.

### 3.4.3.Disease severity

Disease severity was taken on the basis of the percentage of leaf area affected by early and late blight. The reading was started on the onset of late blight (1-5% infection). The 1-9 disease scale described by (Heinfnings, 1987) was used as listed in Appendix Table 5.

### 3.4.4.Tuber physical and chemical quality characters

**Tuber dry matter content (%):** was calculated from the cleaned tubers of each plot. 400 g samples were taken and chopped into small 1-2 cm cubes. The samples were mixed thoroughly and two sub-samples of 200 g of each net plot were taken from them. The exact weight of each sub-sample was recorded as fresh weight. Subsequently, each subsample was placed in an oven set a 70$^{o}$C for 48 hours and dried until constant weight. The weight after dying was recorded as dry weight. The dry matter in percent was calculated according to the formula of Williams and Woodbury (1968).

$$\text{Dry matter}(\%) = \frac{\text{weight of sample after drying}}{\text{Initial weight of sample}} \times 100$$

**Specific gravity of tubers (gcm$^{-3}$)**:- It was determined using the weight in air/weight in water method. Five kilogram tubers of all shapes and sizes were randomly taken from each net plot. The selected tubers were washed with water. First it was weighed in air and then reweighed suspended in water and the specific gravity determined according to the following formula (Kleinkopf *et al*., 1987).

$$\text{Specificgravity} = \frac{\text{weight of tuber in air}}{[(\text{weight of tuber in air}) - (\text{weight of tuber in water})]}$$

**Geometric mean diameter (GMD) (mm):** The sizes of ten randomly sampled tubers from each plot were measured in three tuber dimensions: length, width and thickness using a digital calliperwith an accuracy of 0.01 mm. The geometric mean diameter (Dg) was calculated by using the following equation as described by Mohsenin (1970).

$$\mathbf{Dg} = (L \times W \times T))^{0.333}$$

**Where**: - L= is the length (mm); W= is the width (mm)andT= is thickness of the tuber (mm).

**Number of eyes per Tuber: -** it was determined by counting tuber eyes from ten tubers taken randomly from the net plot and the average was used in analyses.

Chemical quality analyses comprised content of starch, protein and mineral elements (P, Fe and Zn). For each cultivar, three samples (each made of 500 gram tubers from each net plot of the treatment) were used. Potato tubers were analyzed without peeling. Whole unpeeled tubers were sliced, oven dried at 105$^{o}$C until there was no further loss in weight and mixed before analysis. The mineral composition of the samples was evaluated using spectrophotometric methods. Zinc and iron, were determined through Atomic Absorption Spectrophotometry while phosphorus was evaluated through ultra violated spectrophotometry inductively coupled plasma (ICP) according to (AOAC, 1980).Concentrations were expressed on a dry weight (DW) basis.

**Starch content (%)** = this was calculated from tuber dry weight using the formula

17.55 + 0.891 × (tuber dry weight % – 24.182) (AOAC, 1980; Esendal, 1990).

**Total phosphorus percentage:** $\% \, P = \text{ppm} \times \frac{R}{Wt} \times \frac{100}{10000}$

**Where:** ppm is obtained from calibration curve; Wt = Weight of dry plant (g);

R = Ratio between total volume of the digest/aliquot and the digest/aliquot volume used for measurement.

**Iron (mg kg$^{-1}$):** was calculated according to Arsenal (1974).

$$\text{Fe} = \frac{\text{mg of iron as read from curve}}{\text{gramg of sample ln aiiquot x 10}}$$

**Zinc (mg kg$^{-1}$):** was calculated according to (Arsenal, 1974)

$$\text{Zn(ppm)} = (\text{ppm in extract} - \text{blank}) \times \frac{\text{A}}{\text{Wt}}$$

**Where:** A = Total volume of the extract (mL) W = Weight of dry plant (g)

**Total Carotenoid content (%):-** Total carotenoid content (TC) was determined by visible absorption spectrophotometry Model (Cecil CE, 2021) at an absorbance of 450 nm. The concentration of total carotenoids was estimated according to the method reported by Morris *et al*. (2004).

**Crude Proteins (CP)**:- Nitrogen was analyzed by the Kjeldahl method and the average nitrogen (N) content of proteins was found to be about 16 percent, which led to use of the calculation N x 6.25 (1/0.16 = 6.25) to convert nitrogen content into protein content (Van Gelder, 1981).

## 3.5.Statistical Analysis

### 3.5.1.Analysis of variance

Collected data on agronomic and quality characters were subjected to the analysis of variance (ANOVA) of Randomized Complete Block Design (RCBD) by following the procedure outlined by Gomez and Gomez (1984) using SAS software, version 9.1 (SAS, 2002). Mean separation was performed using Duncan's Multiple Range Test (DMRT) at 5% probability level of significance.

Table 2: Analysis of variance of randomized complete block design

| Source of Variation | Degree of Freedom | Sum of Squares | Mean squares | F value (5%) | *p*r > F |
|---|---|---|---|---|---|
| Replication | (r-1)= 2 | SSR | MSR | MSR/MSE | <0.05 |
| Treatment | (t-1)=11 | SST | MST | MST/MSE | |
| Error | (r-1) (t-1)=22 | SSE | MSE | | |
| Total | (rt-1)=35 | | | | |

The model used for RCBD is: $X_{ij} = \mu + T_i + B_j + E_{ij}$

**Where:** $X_{ij}$ = the measured value of the $i^{th}$ treatment in the $j^{th}$ block, $\mu$ = the overall mean (grand mean), $T_i = i^{th}$ treatment effect ($\mu_i$-$\mu$), Bj = $j^{th}$ block effect ($\mu_j$-$\mu$) and $E_{ij}$ =experimental error in the $i^{th}$ treatment and the $j^{th}$ block.

### 3.5.2.Measures of variability

**Phenotypic and genotypic variability**

The traits that exhibited significant mean squares in general ANOVA were further subjected to genetic analyses. Phenotypic and genotypic variances and coefficients of variation, heritability, and genetic advance were computed using the excel Microsoft program. These analyses are elaborated in subsequent sub-titles.The phenotypic and genotypic variances and coefficients of variations were calculated according to the method suggested by Burton and de Vane (1953) as follows:

i. Phenotypic variance ($\sigma^2$ p) = $\sigma^2 g + \sigma^2 e/r$

ii. Genotypic variance ($\sigma^2 g) = \frac{Mg-Me}{r}$

iii. Environmental variance ($\sigma^2 e$) = Me

**Phenotypic and genotypic coefficient of variation**

The phenotypic coefficients of variation (PCV), genotypic coefficients of variation (GCV) and Environmental Coefficient of variation (ECV) were estimated according to the procedure out lined by Johnson *et al*., (1955).

- Phenotypic coefficient of variation (PCV): $PCV\% = \frac{\sqrt{\sigma^2 p}}{\bar{X}} \times 100$
- Genotypic coefficient of variation (GCV): $GCV\% = \frac{\sqrt{\sigma^2 g}}{\bar{X}} \times 100$
- Environmental Coefficient of variation (ECV):ECV% $= \frac{\sqrt{\sigma^2 e}}{\bar{X}} \times 100$

According to Deshmuk *et al.* (1986), PCV and GCV value > 20% are considered as high, while values < 10% are considered low and values between 10% and 20 % are considered medium.

**Where**, $\sigma^2_p$= Phenotypic variance, $\sigma^2_g$= Genotypic variance, $\sigma^2_e$= Environmental (error) variance (Error mean square), Mg = Mean square of genotypes (treatments), Me = Mean square of error, r = Number of replications $\bar{x}$ =grand (population) mean

### 3.5.3.Estimation of heritability in broad sense

Heritability in broad sense was calculated according to the method suggested by Robinson *et al.* (1949). $H^2 = \frac{\sigma^2 g}{\sigma^2 p} \times 100$

Estimates were categorized according to the method suggested by Robinson *et al.* (1949), which categorized $H^2$as low (0-30%), Moderate (30 to 60%) and as high (>60%).

### 3.5.4.Expected genetic advance

Expected genetic advance (GA) in original units of measurement and in present of the mean (GAM) of each trait with one cycle of selection were calculated using the formula adopted by Johnson *et al*., (1955). $GA = K \times \sigma p \times H^2$

Genetic advance as percent of mean was calculated to compare the extent of predicted advances of different traits under selection. $\text{GAM} = \frac{\text{GA}}{\bar{\text{X}}} \times 100$

Where: K = the selection differential (K = 2.06 at 5% selection intensity);

GA = Expected genetic advance, $\sigma$p=Phenotypic standard deviation on mean basis:

$H^2$ = Heritability (Broad sense)

According to Johnson *et al.,* (1955) GAM is categorized as follows: high which are above 20%, moderate (10-20) % and low when less than 10%.

### 3.5.5.Phenotypic and genotypic correlation

Phenotypic ($r_p$) and genotypic ($r_g$) correlations between two traits were computed from variance and covariance components based on the method described by Singh and Chaudhury (1996). The PROC CANDISC correlation test was applied for computing genotypic and phenotypic correlation coefficients using SAS statistical package (SAS Institute, 2002). To estimate phenotypic and genotypic correlation coefficients, covariance analysis between all pairs of traits was first calculated as:

Genotypic covariance between traits x and y $(\sigma gxy) = (MSP\text{g} - MSPe)/r$

Phenotypic covariance between traits x and y $(\sigma\text{p}xy) = \sigma\text{g}xy + \sigma\text{e}xy/r$

Environmental covariance between traits x and y $(\sigma exy) = MSPe$

**Where,** MSPe= Environmental covariance between traits x and y, MSPg = Genotypic covariance between traits x and y r= number of replications.

Phenotypic and genotypic correlation coefficients were then estimated using the standard procedure suggested by Miller *et al*., (1958) from the corresponding variance and covariance components as:

Phenotypic correlation coefficient (rpxy) $= \frac{\sigma pxy}{\sqrt{(\sigma^2 px * \sigma^2 py)}}$

Where, $\sigma^2$px = phenotypic variance for variable x, $\sigma^2$py = phenotypic variance for variable y

Genotypic correlation coefficient ($rgxy$) $= \frac{\sigma gxy}{\sqrt{(\sigma^2 gx * \sigma^2 gy)}}$

Where; rpxy= phenotypic correlation coefficient between characters x and y, rgxy = genotypic correlation coefficient between characters x and y

$\sigma^2$gx = Genotypic variance for variable x, $\sigma^2$gy = genotypic variance for variable y

The calculated phenotypic correlation value was tested for its significance using t-test was determined from correlation table at appropriate degrees of freedom and probability level Gomez and Gomez, (1984).

The coefficients of correlations at genotypic levels were tested for their significance by the formula described by Robertson (1959) as indicated below:

$$t = \frac{r_{gxy}}{SEr_{(gxy)}}$$

The calculated "t" value was compared with the tabulated "t" value at (n-2) degree of freedom at 5% level of significance. Where, n is number of genotypes.

$$SEr_{(gxy)} = \sqrt{\frac{1 - r^2 gxy}{h^2 x * h^2 y}}$$

Where, $h^2$x = Heritability of trait x $h^2$y = Heritability of trait y

### 3.5.6.Path coefficient analysis

Path coefficient analysis helps to show the cause and effect relationship between yield and its components. It was carried out according to Dewey and Lu (1959). Direct and indirect effects of different characters were calculated at both genotypic and phenotypic levels.

$$\mathbf{rij = Pij + \Sigma rikPkj}$$

Where, **rij** is association between the independent variable (i) and dependent variable (j) as measured by correlation coefficient; Pij is component of direct effect of the independent variable (i) on the dependent variable (j) as measured by path coefficient; and Σrik Pkj is summation of components of indirect effects of a given independent variable (i) on a given dependent variable (j) via all other independent character (k). To determine Pij values square matrices of the correlation coefficients between independent characters in all possible pairs were inverted and then multiplied by the correlation coefficient between independent and dependent characters. The residual effect was estimated as described in Dewey and Lu (1959):- Residual effect=$\sqrt{1-R^2}$

$$R^2 = \mathbf{\Sigma Pij\ rij}$$

### 3.5.7.Cluster analysis (CA)

Cluster analysis was also performed to group sets of genotypes with similar characteristics into homogenous groups. Genetic distance of 12 potato cultivars were estimated using Euclidean distance (ED) calculated from quantitative and qualitative traits. Hierarchical clustering was employed using the similarity coefficients among the cultivars. The number of clusters was determined and cluster analysis was performed by MINITAB version 17 statistical computer packages. It also was employed to summarize the observation by constructing Dendrogram (Webster and Oliver, 1990).

# 4. RESULTS AND DISCUSSIONS

## 4.1. Analysis of variance

The results of analysis of variance showed the presence of very highly significant ($P \leq 0.001$) and highly significant ($P \leq 0.01$) differences among the 12 potato cultivars studied across all characters except for days to maturity where it indicated significant ($P \leq 0.05$) variation (Table 3). This indicated the existence of substantial level of variability among cultivars in the traits considered; variability that can be utilized in future breeding to improve agronomic traits and nutritional quality of potato following appropriate breeding methods.

These findings were in agreement with the findings of various authors reported earlier. Addisu *et al*. (2013) reported highly significant differences among cultivars for days to emergence, days to 50% flowering, days to 90% maturity, plant height, tuber number per plant, average tuber yield per plant, big tubers and small tuber size grades. Similarly, Sattar *et al*. (2007) reported a wide range of variation among potato genotypes in Bangladesh in plant height and in days to 50% maturity. Nasiruddin *et al.* (2017) also reported significant difference among potato varieties in plant height, number of stems per plant, tuber dry matter, number of tubers per plant and average tuber weight. Getachew *et al*. (2016) reported highly significant difference between potato varieties in days to flowering, days to maturity, plant height, number of stems per plant, total tuber yield, marketable tuber yield, unmarketable tuber yield, average tuber number, percentage of big tubers, medium tubers, late blight resistance and small tubers. Mitiku *et al.* (2014) also reported significant difference among the tested potato varieties in average tuber weight, large size tuber, average tuber weight and tuber yield. Tekola, (2014) also reported highly significant differences with respect to days to emergence, days to 50% flowering, days to 90% maturity, plant height, number of stem per plant, number of tubers per plant, weight and number of marketable tuber, weight and number of unmarketable tuber and total starch content. Ebrahim, (2018), Habtamu *et al*. (2016) and Wassu (2017) reported highly significant difference among potato genotypes for tuber quality characters and late blight disease resistant among 17 potato varieties. Consistent with our results, Wassu (2016) also reported significant variation in tuber dry matter content among seventeen potato cultivars tested at three locations. Various researchers reported the existence of significant variation among potato cultivars in physical and chemical quality traits. Lemma (2018) reported significant variation between potato genotypes in starch content and in dry weight at two locations. Tesfaye *et al.* (2012) reported that Fe, Zn, P and total protein concentration showed significant variation among potato cultivars. Similarly Bonierbale *et al.* (2011) reported significant difference between potato genotypes in Fe concentration. Ekin (2011) found highly significance difference among potato varieties in Fe and Zn concentration. Andre *et al.* (2007) also reported highly significant difference among potato cultivars in tuber quality characters such as carotenoid content.

Table 3: Mean squares from ANOVA for the 27 traits including yield, yield components and quality character of 12 potato cultivars evaluated at Debre Birhan in 2017.

| Character | Replications (d.f.=2) | Cultivar (d.f.=11) | Error (d.f.=22) | CV % | $R^2$ (%) |
|---|---|---|---|---|---|
| Late blight Severity | 243.8 | 1398.7*** | 161.2 | 18.0 | 82 |
| Early blight Severity | 21.5 | 70.9** | 16.2 | 46.8 | 70 |
| Emergency date | 0.4 | 29.5*** | 1.8 | 21.4 | 89 |
| Days to 50% flowering | 13.0 | 156.3*** | 10.0 | 4.3 | 89 |
| Days to maturity | 44.3 | 103.6* | 35.9 | 5.1 | 61 |
| Plant height (cm) | 61.2 | 247.0*** | 26.2 | 10.3 | 83 |
| Average tuber number per hill | 13.0 | 27.0** | 2.1 | 13.7 | 87 |
| Average tuber weight (g/tuber) | 4.7 | 788.0** | 41.3 | 11.0 | 91. |
| Marketable tuber yield (t $ha^{-1}$) | 21.6 | 149.6** | 3.7 | 8.2 | 95 |
| Number of marketable tuber $ha^{-1}$ (in 1000 base) | 2724.0 | 20875.0** | 709.5 | 8.5 | 94 |
| Unmarketable tuber yield (t $ha^{-1}$) | 2.0 | 9.0** | 0.8 | 45.7 | 85 |
| Number of unmarketable tuber $ha^{-1}$ (in 1000 base) | 14211.0 | 59993.0** | 4420 | 43.0 | 88 |
| Total tuber yield (t $ha^{-1}$) | 35.9 | 115.4** | 3.7 | 7.5 | 94 |
| Number of total tuber $ha^{-1}$ (in 1000 base) | 28008.0 | 52225.0** | 4987 | 15.0 | 85 |
| Large tuber yield (t $ha^{-1}$) | 9.5 | 111.0** | 3.9 | 11.0 | 94 |
| Large size tubers (%) | 20.6 | 404.0** | 24 | 7.0 | 89 |
| Medium tuber yield (t $ha^{-1}$) | 1.3 | 9.2** | 0.95 | 20.0 | 83 |
| Medium size tubers (%) | 4.8 | 102.0** | 13.8 | 20.0 | 79 |
| Small tuber yield (t $ha^{-1}$) | 3.7 | 9.4** | 1 | 32.8 | 83 |
| Small size tubers (%) | 10.8 | 292.0** | 11.8 | 26.0 | 92 |
| Dry matter content (%) | 0.6 | 8.3** | 0.7 | 3.8 | 86 |
| Specific gravity of tubers ($gcm^{-3}$) | 0.00009 | 0.00025** | 0.00003 | 0.5 | 80 |
| Numbers of eyes pertuber | 0.6 | 3.1** | 0.8 | 12.0 | 67 |
| Geometric mean diameter ($mm^3$) | 19.0 | 108.5** | 22 | 11.8 | 72 |
| Starch content (g/100g) | 0.5 | 6.6** | 0.6 | 4.8 | 86 |
| Phosphorous% age | 0.0013 | 0.099** | 0.017 | 12.5 | 75 |
| Iron (mg/kg) | 7.4 | 272.0** | 31 | 15.0 | 81 |
| Zinc(mg/kg) | 155.0 | 262.0** | 40.7 | 17.5 | 78 |
| Total Carotinoids µg/g | 1.22 | 12.1** | 3.2 | 7.7 | 66 |
| Crude Protein in % | 0.03 | 5.1** | 0.27 | 5.3 | 90 |

*** - Significant at P<0.001, ** - Significant at P<0.01, * - Significant at P<0.05 and ns - non-significant, number in parenthesis represented degree of freedom for the respective source of variation.

## 4.2.Range and Mean Performances of Cultivars

### 4.2.1.Mean Performance of cultivars for phenology and growth characters

The results of the computed values for the statistical parameters like means, maximum and minimum values for all the studied characters of 12 potato cultivars are presented in Table 4. The cultivars showed wide ranges of 28.3 % to 91.7 % and 5 % to 20 % for late blight Severity percentage and early blight Severity percentage with the mean performance of 70.4 % and 8.6 %, respectively. Days to 50% flowering ranged from 63 to 80 days with a mean of 73 days Table 5. The released cultivar except Bubu, Alemaya 624 and Awash took the shortest time to flower; with mean days to flowering of from 63 to 66 days. The cultivars that took longer time to reach 50% flowering stage were all farmers' cultivars, Bubu, Alemaya 624 and Awash, i.e., 75.7 to 80 days. Days to maturity ranged from 109 to 128 with a mean of 118 days. According to category for days to maturity set by Muhinyuza *et al*., (2014), none of the studied 12 cultivars fall under early maturity group, i.e.., varieties maturing in less than 90 days. Hence, there was no early maturing cultivar from both the farmers' cultivars as well as from the released varieties. However, 66.7% of the cultivars studied have fallen under medium maturity category taking between 90 and120 days to reach physiological maturity, while 33.3% of the cultivars have fallen under the late maturing groups taking more than 120 days to reach maturity. Four of the 12 studied cultivars (Enatbeguaro and Keydinich from the farmers' cultivars and Bubu and Awash from the released cultivars) took the longest durations to mature (>122 days).

Average plant height varied from 38.3 to 68.3 cm with a mean height of 50 cm. The released varieties Gera (45.7 cm) and Awash (40.5 cm) had the lowest plant height.The maximum height of 68.3 cm was recorded from Enatbeguaro while the shortest plant height of 38.3 cm was recorded from keydinich (Table 5). Farmers' varieties were the latest to emerge (23 vs 21 days), in days to flowering (75 vs 71 days), and in days to maturity (123 vs 120 days) but did not differ in plant height (50 vs 50 cm) as compared to the released varieties. Differences in days of emergency, days of flowering and days of maturity between the two groups were very highly significant (results of a one degree of freedom contrast not presented). The released varieties were more susceptible to late blight (74 vs 63) than farmers' cultivars ($P<0.05$) but the two groups did not differ in their tolerance to early blight (8.7 vs 8.8). Enatbeguaro (28.3%) had the lowest late blight severity while all remaining varieties had late blight severity ranging from 40% (Gera) to 91.7% (Shenkola). Seven of the varieties (58.3%) had late blight severity of higher than 80%. Dinkey (90%), Gorebella and Belete (86.7%) were also very susceptible to late blight infestation. To the contrary Gera, Bubu, and Keydinich were relatively tolerant to this disease (40.0 to 53.3% severity). Early blight severity ranged from 5.0 (six varieties) to 20.0% (Enatbeguaro). Varieties which were more tolerant to late blight such as Enatbeguaro Gera and Bubu were the most susceptible to early blight (8.3 to 20% severity).

Accordingly, many authors also reported the significant variation among potato cultivars for days to flowering, days to maturity and plant height. Addisu *et al*. (2013) reported that days to flowering and days to maturity were ranged within 50 to 70.5, 97 to 116 and 26.7 to 99,with the mean of 60, 108.8 and 78 days, respectively. Getachew *et al*. (2016) also reported 55 to 69 and 98 to119 days to flowering and maturity, respectively. Khayatnezhad *et al.* (2011) reported that days for 50% flowering and days to 90% vary from 60-70.5, 97-116, whereas height of potato plants 28.4 to 71.2 cm. Abraham (2013) reported 50.0 to 63.3, and 90.0 to 118.0 days to flowering and maturity, respectively, that were evaluated in southern Ethiopia.

Table 4: Minimum, maximum, mean and range ofdifferent charactersof 12 potato cultivars evaluated at Debre Birhan in 2017

| Character | Maxi mum | Minim um | Mean | Range | Range in% mean |
|---|---|---|---|---|---|
| Late blight Severity | 91.7 | 28.3 | 70.4 | 63.4 | 90 |
| Early blight Severity | 20.0 | 5.0 | 8.6 | 15.0 | 174 |
| Emergency date | 25.3 | 14.7 | 21.4 | 10.6 | 50 |
| Days to 50% flowering | 79.7 | 63.0 | 72.5 | 16.7 | 23 |
| Days to maturity | 128 | 109.0 | 117.7 | 19 | 16 |
| Plant height (cm) | 68.3 | 38.3 | 49.8 | 30 | 60 |
| Average tuber number per hill | 16.0 | 5.7 | 10.6 | 10.3 | 97 |
| Average tuber weight (g/tuber) | 81.0 | 26.7 | 58.2 | 54.3 | 93 |
| Marketable tuber yield (t $ha^{-1}$) | 36.14 | 12.06 | 23.55 | 24.08 | 102 |
| Number of marketable tuber $ha^{-1}$ (in 1000 base) | 417 | 195 | 424 | 222 | 52 |
| Unmarketable tuber yield (t $ha^{-1}$) | 6.52 | 0.72 | 1.99 | 5.8 | 291 |
| Number of unmarketable tuber $ha^{-1}$ (in 1000 base) | 498 | 46 | 153.3 | 452 | 295 |
| Total tuber yield (t $ha^{-1}$) | 36.86 | 16.3 | 25.53 | 20.56 | 81 |
| Number of total tuber $ha^{-1}$ (in 1000 base) | 693 | 256 | 467 | 437 | 94 |
| Large tuber yield (t $ha^{-1}$) | 30.7 | 7.45 | 17.65 | 23.3 | 132 |
| Large size tubers (%) | 307 | 94 | 190 | 213 | 112 |
| Medium tuber yield (t $ha^{-1}$) | 6.95 | 1.8 | 4.77 | 5.2 | 108 |
| Medium size tubers (%) | 135 | 36 | 90 | 99 | 110 |
| Small tuber yield (t $ha^{-1}$) | 7.45 | 1.46 | 3.1 | 6 | 193 |
| Small size tubers (%) | 530 | 79 | 188 | 451 | 240 |
| Dry matter content (%) | 24.2 | 17.7 | 21.9 | 6.5 | 30 |
| Specific gravity of tubers (gcm-3) | 1.096 | 1.064 | 1.085 | 0.032 | 3 |
| numbers of eyes per | 9.7 | 5.7 | 7.5 | 4 | 53 |
| Geometric mean diameter ($mm^3$) | 50.5 | 26.7 | 39.7 | 23.8 | 60 |
| Starch content (g/100g) | 17.5 | 11.7 | 15.5 | 5.8 | 37 |
| Phosphorous% age | 1.3 | 0.6 | 1.03 | 0.7 | 68 |
| Iron (mg/kg) | 48 | 21.5 | 36.1 | 26.5 | 73 |
| Zinc(mg/kg) | 48.5 | 22.5 | 36.5 | 26 | 71 |
| Total Carotinoids µg/g | 27.4 | 20.7 | 23.3 | 6.7 | 29 |
| Crude Protein in % | 12.31 | 8.11 | 10 | 4.2 | 43 |

Table 5: Mean performance of 12 potato cultivars for phenology and growth parameters at Debre Birhan in 2017

| Cultivar | Late blight Severity | early blight Severity | Emergency date | Days to flowering | Days to maturity | Plant height (cm) |
|---|---|---|---|---|---|---|
| Alemaya 624 | $70.0^{bc}$ | $11.7^{bc}$ | $22.3^{cd}$ | $75.7^{a}$ | $115.7^{bcde}$ | $54.3^{bc}$ |
| Awash | $80.0^{ab}$ | $5.0^{c}$ | $23.0^{bc}$ | $79.0^{a}$ | $128.0^{a}$ | $40.7^{e}$ |
| Menagesh | $91.7^{a}$ | $5.0^{c}$ | $18.0^{g}$ | $63.0^{b}$ | $117.3^{abcde}$ | $52.3^{c}$ |
| Gorebella | $53.3^{dc}$ | $5.0^{c}$ | $20.0^{efg}$ | $63.0^{b}$ | $116.3^{bcde}$ | $52.3^{c}$ |
| Gera | $51.7^{dc}$ | $8.3^{bc}$ | $21.7^{cde}$ | $66.0^{b}$ | $110.3^{de}$ | $45.7^{cde}$ |
| Shenkolla | $83.3^{ab}$ | $8.3^{bc}$ | $14.7^{h}$ | $65.0^{b}$ | $109.0^{e}$ | $51.0^{cd}$ |
| Belete | $83.3^{ab}$ | $5.0^{c}$ | $19.3^{fg}$ | $65.3^{b}$ | $113.7^{cde}$ | $50.3^{cd}$ |
| Bubu | $40.0^{de}$ | $15^{ab}$ | $20.3^{def}$ | $77.7^{a}$ | $123.0^{abc}$ | $62.0^{ab}$ |
| Keydinich | $90.0^{ab}$ | $5.0^{c}$ | $24.7^{ab}$ | $79.3^{a}$ | $121.7^{abcd}$ | $38.3^{e}$ |
| Enatbeguaro | $28.3^{e}$ | $20.0^{a}$ | $23.3^{abc}$ | $79.7^{a}$ | $124.7^{ab}$ | $68.3^{a}$ |
| Akime | $86.7^{ab}$ | $10.0^{bc}$ | $24.7^{ab}$ | $79.0^{a}$ | $119.7^{abcde}$ | $42.0^{de}$ |
| Dinkey | $86.7^{ab}$ | $5.0^{c}$ | $25.3^{a}$ | $77.3^{a}$ | $112.7^{cde}$ | $40.7^{e}$ |
| Range | 28.3-91.7 | 5-20 | 14.7-25.3 | 63-79.7 | 109-128 | 38.3-68.3 |
| Mean | 70.4 | 8.6 | 21.4 | 72.5 | 117.7 | 49.8 |
| CV | 18 | 46.8 | 6.2 | 4.3 | 5 | 10.2 |
| Level of significance | *** | ** | *** | *** | * | *** |

Means followed by the same letter within a column are not significantly different at the prescribed level of probability.

*** = Very highly significant at 0.1% ** = highly significant at 1%, * = significant at 5% and ns = non significant at 1% and 5%.

### 4.2.2. Mean performances of cultivars for yield components

The studied potato cultivars had displayed a wide range of variation in tuber yield component parameters like average tuber numbers per hill and average tuber weight which ranged from 5.7 to 16 and 26.7 to 81 gram with a mean of 10.6 and 58 gram, respectively. Cultivar Keydinich had the maximum number of tuber per hill with values of 16. While Dinkey gives the lowest tuber numbers per hill 5.7 tubers per hill. Bubu (81 gram) and Keydinich (26.7 gram) produced the highest and the lowest average tuber weight. Farmers' varieties were more numbers of tuber per hill (11 vs 10 tubers), but average tuber weight of the released varieties had highest than farmers' cultivar (61 vs 52 grams), Number of marketable tuber ranged from 195 tubers $ha^{-1}$ (Keydinich) to 417 tubers $ha^{-1}$ (Shenkolla) with an overall mean of 314 tubers $ha^{-1}$. The highest number of unmarketable tubers $ha^{-1}$ 498 tubers $ha^{-1}$ was counted in cultivar keydinich. While, the minimum number of unmarketable tuber $ha^{-1}$ 46, which were counted in released variety Bubu, with an overall mean of 153 tubers $ha^{-1}$. Released cultivars had more numbers of marketable tubers than farmers' cultivars, 50 % of cultivars from released cultivars and only 8.3 % of farmers' cultivars showed more marketable tubers value than from mean performance. But 50 % of farmers' cultivars and 12.5 % of released cultivars showed higher unmarketable tubers value than the mean. The number of total tubers $ha^{-1}$ ranged from 256 to 693 with an overall mean of 467. The highest number of total tuber per $ha^{-1}$ was found in cultivar keydinich 693, which is statistically similar to cultivar Akime (651), and Shenkolla (579). The lower number of total tuber yield per $ha^{-1}$ was found in Dinkey (256) Table (6). The above figures for all marketable, unmarketable and total numbers of tubers $ha^{-1}$ was in 1000 base. Similar to this study, Rangare and Rangare (2017) reported 2.93 to7.51 numbers of stem per plant. Fekadu *et al*. (2013) also showed that the genotypes value ranged from 3.8 to 9.7 and 10.1-24.4 for number of stems per plant and tubers number per plant, respectively.

Tuber size distribution showed highly significant ($P < 0.01$) differences among potato cultivars in the present study as seen in Table 7. Large tuber size number was calculated by counting tubers which weighed >75 g. Tubers weighing 35g to 75g were categorized as medium size while tubers weighing less than 35g were categorized as small size and calculated in number as suggested by Lung'aho *et al*. (2007), and converted to ton $ha^{-1}$ and percentage level for each treatment and the result is presented in Table 7**.** Accordingly, large-sized tubers percent varied from 83.33% to 40.7 % with the total means of 68.1 %. Bubu produced significantly higher percent of large-sized tubers (83.33%). Keydinich had the lowest percent of large-sized tubers $ha^{-1}$ that was 40.7 %. The yield of large-sized tubers value varied from 7.45 ton $ha^{-1}$ to 30.7 ton $ha^{-1}$ with the mean of 17.65 ton $ha^{-1}$. The highest large-sized tubers yield of 30.7 t $ha^{-1}$ was obtained from Bubu variety. On the other hand, the lowest large-sized tubers yield of 7.45 ton $ha^{-1}$ was recorded from cultivar Keydinich. Most of the tested released varieties were found to be better in large-sized tubers yield than the farmer cultivars (Table 7). From the eight released varieties, 2 (25%) of them had lower number of large-sized tubers and yield performance and 3 (75%) of farmers cultivar except Enatbeguaro were characterized by lower percent of large-sized tubers and yield than the grand mean value.

The value of medium sized tubers percent varied from 9.7 % to 29.7 % with the mean of 18.6 %. The highest percent of medium-sized tubers was obtained from the improved variety Shenkolla (29.7 %). Dinkey and Menagesha had the lowest percent of medium-sized tubers 9.7 % and 11.3 %, respectively. The yield of medium-sized tubers value varied from 1.8 ton $ha^{-1}$ to 6.95 ton $ha^{-1}$ with the mean of 4.77 ton $ha^{-1}$. The highest medium-sized tubers yield of 6.95 ton $ha^{-1}$ was recorded from the improved variety Shenkolla. Conversely, the lowest medium-sized tubers yield of 1.8 ton $ha^{-1}$ was recorded from the farmers' cultivar Dinkey (Table 7). Medium-sized tubers are appropriate for planting.

Table 6: Mean performance of 12 potato cultivars for yield component evaluated at Debre Birhan in 2017

| Cultivar | Tuber number per hill | Average tuber weight | Number of Marketable tuber | Number of Unmarketable tuber | Number of total tuber |
|---|---|---|---|---|---|
| Alemaya 624 | $11.7^{cd}$ | $50.3^{d}$ | $380^{abc}$ | $142^{b}$ | $521^{bc}$ |
| Awash | $9.0^{de}$ | $49.7^{d}$ | $292^{ef}$ | $103^{b}$ | $395^{cd}$ |
| Menagesh | $6.7^{ef}$ | $72.0^{ab}$ | $200^{g}$ | $81^{b}$ | $281^{de}$ |
| Gorebella | $10.7^{cd}$ | $64.7^{bc}$ | $384^{abc}$ | $92^{b}$ | $476^{bc}$ |
| Gera | $9.7^{d}$ | $75.7^{ab}$ | $346^{cd}$ | $71^{b}$ | $416^{c}$ |
| Shenkolla | $13.3^{bc}$ | $52.0^{d}$ | $417^{a}$ | $162^{b}$ | $579^{ab}$ |
| Belete | $10.7^{cd}$ | $59.3^{cd}$ | $362^{bcd}$ | $113^{b}$ | $475^{bc}$ |
| Bubu | $10.3^{d}$ | $81.0^{a}$ | $410^{ab}$ | $46^{b}$ | $456^{bc}$ |
| Keydinich | $16.0^{a}$ | $26.7^{e}$ | $195^{g}$ | $498^{a}$ | $693^{a}$ |
| Enatbeguaro | $9.3^{d}$ | $68.3^{bc}$ | $322^{de}$ | $83^{b}$ | $406^{cd}$ |
| Akime | $14.7^{a}$ | $35.0^{e}$ | $262^{f}$ | $389^{a}$ | $651^{a}$ |
| Dinkey | $5.7^{f}$ | $64.0^{bc}$ | $196^{g}$ | $59^{b}$ | $256^{e}$ |
| Range | 5.7-16 | 26.7-81 | 195-417 | 46-498 | 256-693 |
| Mean | 10.6 | 58 | 314 | 153 | 467 |
| CV | 13.7 | 11 | 8.5 | 43 | 15 |
| Level of Significance | ** | ** | ** | ** | ** |

Means followed by the same letter within a column are not significantly different at the prescribed level of probability. ** =significant at 1%, * = significant at 5% and ns = non significant at 1% and 5%. Numbers of tubers were in 1000 base.

The highest and the lowest percent of small sized tubers were obtained from farmer's cultivar. The highest percent of small tubers size was 39.7 % and it was obtained from keydinich. Dinkey produced the lowest (8.3 %) proportion of small sized tubers compared to the other cultivars. The grand mean of small tubers sized percent was 13.2 %. The highest and lowest small sized tubers yield showed highly significant difference. Cultivar Keydinich (7.45 tons $ha^{-1}$) was the highest in small sized tubers yield, while Dinkey (1.46 tons $ha^{-1}$) was the lowest in small sized tubers yield. The overall mean for small sized tubers yield was 3.11 tons $ha^{-1}$. Various researchers reported significant variation among Potato genotypes for tuber yield components. As Mekonen *et al*. (2009) who reported significant differences among genotypes for number of tuber per plant. Chala (2018) reported the mean value of average tuber number per hill, proportion of very small and larger tuber sizes were ranged from 3.13 to 20.14, 0.167 to 0.42 and 0.12 to 0.42, respectively, and with mean value of 10.84, 0.27 and 0.26 in that order. Ebrahim (2018) showed that the highest and significantly different mean values were recorded from 7.18 to 18.46 and 89.11 to 40.41 g, with the mean of 40.75g and 41.2 g for average tuber number of per hill and average tuber weight, respectively.

Table 7: Mean performance of 12 potato cultivars for tuber size distribution evaluated at Debre birhan in 2017

| Cultivar | Large tuber yield in ton ha$^{-1}$ | Large size tubers (%) | Medium tuber yield | Medium size tubers (%) | small tuber yield in ton ha$^{-1}$ | Small size tubers (%). |
|---|---|---|---|---|---|---|
| Alemaya 624 | 17.67$^{cd}$ | 67.3$^{cd}$ | 5.56$^{ab}$ | 21.0$^{bc}$ | 2.95$^{b}$ | 11.0$^{c}$ |
| Awash | 11.63$^{f}$ | 59.0$^{de}$ | 5.86$^{ab}$ | 29.7$^{a}$ | 2.16$^{b}$ | 11.0$^{c}$ |
| Menagesh | 16.06$^{de}$ | 80.0$^{ab}$ | 2.00$^{de}$ | 11.3$^{d}$ | 2.10$^{b}$ | 10.3$^{c}$ |
| Gorebella | 21.19$^{bc}$ | 70.3$^{c}$ | 6.33$^{a}$ | 21.0$^{bc}$ | 2.65$^{b}$ | 8.3$^{c}$ |
| Gera | 22.85$^{b}$ | 73.0$^{bc}$ | 6.00$^{ab}$ | 19.3$^{bc}$ | 2.41$^{b}$ | 8.0$^{c}$ |
| Shenkolla | 19.45$^{bcd}$ | 65.3$^{cde}$ | 6.95$^{a}$ | 23.3$^{b}$ | 3.41$^{b}$ | 11.0$^{c}$ |
| Belete | 19.93$^{bc}$ | 70.00$^{c}$ | 5.85$^{ab}$ | 21.0$^{bc}$ | 2.60$^{b}$ | 9.0$^{c}$ |
| Bubu | 30.70$^{a}$ | 83.3$^{a}$ | 4.15$^{bc}$ | 11.3$^{d}$ | 2.00$^{b}$ | 5.7$^{c}$ |
| Keydinich | 7.45$^{g}$ | 40.7$^{f}$ | 3.67$^{cd}$ | 19.7$^{bc}$ | 7.45$^{a}$ | 39.7$^{a}$ |
| Enatbeguada | 19.00$^{cd}$ | 70.0$^{c}$ | 5.93$^{ab}$ | 21.7$^{bc}$ | 2.22$^{b}$ | 8.3$^{c}$ |
| Akime | 12.81$^{ef}$ | 58.39$^{e}$ | 3.13$^{cde}$ | 14.7$^{cd}$ | 5.92$^{a}$ | 26.7$^{b}$ |
| Dinkey | 13.03$^{ef}$ | 79.7$^{ab}$ | 1.80$^{e}$ | 9.7$^{d}$ | 1.46$^{b}$ | 9.0$^{c}$ |
| Range | 7.45-30.7 | 40.7-83.3 | 1.8-6.95 | 36-135 | 1.46-7.45 | 5.7-39.7 |
| Mean | 17.65 | 68.1 | 4.77 | 18.6 | 3.11 | 13.2 |
| CV | 11.0 | 10.8 | 20.4 | 20.0 | 32.8 | 26.0 |
| Level of significance | ** | ** | ** | ** | ** | ** |

Means followed by the same letter within a column are not significantly different at the prescribed level of probability. ** =significant at 1%, * = significant at 5% and ns = non significant at 1% and 5%.

### 4.2.3.Mean Performances of cultivars for tuber yield

The marketable tuber yield varied from 12.06 ton ha$^{-1}$ to 36.14 ton ha$^{-1}$ with an overall mean of 23.55 ton ha$^{-1}$. The highest marketable tuber yield of 36.14 ton ha$^{-1}$ was recorded from the improved variety Bubu. Conversely, the lowest marketable tuber yield of 12.06 ton ha$^{-1}$ was recorded from farmer's cultivar Keydinich. Most of the released varieties were found to producing better marketable yield than most of the farmers' cultivars. From the eight released varieties, 6 (75%) except Menagesha and Awash had better marketable tuber yield performance whereas 3 (75%) of farmer's cultivar except Enatbeguaro had lower marketable tuber yield than the grand mean value. Enatbeguaro cultivar had higher marketable tuber yield (25.99) than all farmer's cultivar and two released variety (Awash- 18.25 ton ha$^{-1}$ and Menagesha (18.99 ton ha$^{-1}$) (Table 8). The unmarketable tuber yield ranged from 0.72 ton ha$^{-1}$ to 6.52 ton ha$^{-1}$ with an overall mean of 1.99 ton ha$^{-1}$. The lowest unmarketable tuber yield was obtained from the improved variety Bubu (0.72 ton ha$^{-1}$). However the highest unmarketable yield was recorded from the farmers' cultivar Keydinich (6.52 t ha$^{-1}$). The studied potato cultivars had also displayed a wide range of variation in their total tuber yield which ranged from 16.28 ton ha$^{-1}$ to 36.86 ton ha$^{-1}$ with overall mean performance of 25.53 ton ha$^{-1}$ (Table 8). The highest total tuber yield was still recorded from the improved variety Bubu (36.86 ton ha$^{-1}$). The lowest total tuber yield of 16.28 ton ha$^{-1}$ was recorded from the farmers' cultivar Dinkey. The two farmer's cultivars Akime and Enatbeguaro gave total tuber yield of 21.86 and 27.15 ton ha$^{-1}$, respectively which were higher than the mean tuber yield of the two released varieties Awash ( 19.65 ton ha$^{-1}$) and Menagesha (20.16 ton ha$^{-1}$). Enatbeguaro had also gave more total yield than Alemaya 624 variety that gave 26.19 ton ha$^{-1}$ (Table 8). The released cultivars had more marketable and total tuber than farmers' cultivars.

But 50% of farmers' cultivars and only one 12.5 % of released cultivars had more unmarketable tubers than the mean value. The released cultivars total tuber yield increment was due to high marketable tuber yield and this trait determine the direction of potato breeding in the last 5-6 decades.

This result is in agreement with the findings of Mekonen *et al*. (2009) who reported significant differences among genotypes for marketable tuber yield per plot and total tuber yield per plot was obtained. Getachew *et al*. (2016) reported 0.06 to 43.7 t $ha^{-1}$ and 0.8 to 46.1 t $ha^{-1}$ of marketable tuber yield and total tuber yield, respectively, for 24 potato genotypes evaluated in Bale highlands, South Eastern Ethiopia. Asmamaw (2007) reported tuber yield variation of 15.54 to 34.37 t ha-1 in northern Ethiopia. Habtamu *et al.* (2016a) also reported a total tuber yield variation of 18.34 to 48.29, 26.71 to 43.50 and 17.70 to 56.52 t ha-1 at Haramaya, Arbarakete and Hirna, respectively in eastern Ethiopia. Rangare and Rangare (2017) evaluated 44 potatogenotypes and reported the presence of significant variation among genotypes for total tuberyield, marketable tuber yield and unmarketable tuber yield.

Table 8: Mean performance of 12 potato cultivars for tuber yield evaluated at Debre Birhanin 2017

| Cultivar | Marketable tuber yield ton $ha^{-1}$ | Unmarketable tuber yield ton $ha^{-1}$ | Total tuber yield ton $ha^{-1}$ |
|---|---|---|---|
| Alemaya 624 | $24.56^{d}$ | $1.63^{c}$ | $26.19^{d}$ |
| Awash | $18.25^{e}$ | $1.4^{c}$ | $19.65^{ef}$ |
| Menagesh | $18.99^{e}$ | $1.18^{c}$ | $20.17^{e}$ |
| Gorebella | $28.81^{bc}$ | $1.37^{c}$ | $30.18^{bc}$ |
| Gera | $30.16^{b}$ | $1.11^{c}$ | $31.27^{b}$ |
| Shenkolla | $27.57^{bcd}$ | $2.24^{c}$ | $29.81^{bc}$ |
| Belete | $27.07^{bcd}$ | $1.32^{c}$ | $28.38^{bcd}$ |
| Bubu | $36.14^{a}$ | $0.72^{c}$ | $36.86^{a}$ |
| Keydinich | $12.06^{f}$ | $6.52^{a}$ | $18.58^{ef}$ |
| Enatbeguada | $25.99^{cd}$ | $1.16^{c}$ | $27.15^{cd}$ |
| Akime | $17.42^{e}$ | $4.45^{b}$ | $21.86^{e}$ |
| Dinkey | $15.52^{e}$ | $0.76^{c}$ | $16.28^{f}$ |
| Range | 12.06-36.14 | 0.72-6.52 | 16.28-36.86 |
| Mean | 23.55 | 1.99 | 25.53 |
| CV | 8.0 | 45.6 | 7.5 |
| Level of significance | ** | ** | ** |

Means followed by the same letter within a column are not significantly different at the prescribed level of probability. ** =significant at 1%, * = significant at 5% and ns = non significant at 1% and 5%.

### 4.2.4.Mean performances of cultivars for physically analyzed quality parameters

The dry matter content partly determines the texture and oiliness of the finished products, thus determining consumer preference. Potatoes with a dry matter content of 20-24% are ideal for making French fries while those with a dry matter content of up to 24% are ideal for preparing crisps (Kabira and Berga, 2003). Significantly higher tuber dry matter content was recorded for Bubu with values of 24.1%. The overall mean values for tuber dry matter contents of all cultivars were 21.9 %. However, the cultivar which had the lowest tuber dry matter content was Keydinich whose mean was 17.7% (Table 9). Thus, all the tested farmer's cultivar and released varieties dry matter content of potato was above 20% indicating their suitability for processing except that of Keydinich 17.7%.

Specific gravity which is an expression of density is the most widely accepted measurement of potato quality. Specific gravity is the measure of choice for estimating dry matter and starch content and ultimately for determining the processing quality of potato varieties (Tesfaye *et al.,* 2013). Good quality potatoes should have a specific gravity value of more than 1.080. Potato tubers with specific gravity values less than 1.070 are generally unacceptable for processing (Kabira and Berga, 2003). The cultivar Keydinich had the lowest specific gravity value of 1.064. The maximum specific gravity of 1.096 was recorded from Gera. In this study, all cultivars had a specific gravity higher than 1.070 indicating their suitability for chips making except keydinich.

More eyes produce more stems. Since each stem is an independent production unit, an increase in their number will consequently translate to more tubers per plant (Shayanowako *et* *al*., 2014). The maximum number of eyes per tuber of 9.7 was recorded on Awash while Gorebella had the lowest number of eyes per tuber with values of 5.7. The overall average was 7.5 eyes per tuber. Mean performance of geometric diameters showed highly significant ($P < 0.01$) difference among the cultivars (Table 9). Dinkey had the highest geometric mean diameter (50.5 $mm^3$) as compared to other varieties while Keydinich had the lowest (26.7 $mm^3$). The overall mean was 39.7 $mm^3$ 2 (50%) farmers' cultivars and 3 (37.5 %) improved varieties had below average geometric mean diameter, and hence had low quality French fries and crisps. This is due to the fact that potato processing industry demands tuber grade > 50 $mm^{-3}$ for French fries and 40 to 65 $mm^{-3}$ for crisps. When tubers are marketed for industrial processing, the portions of certain size-grades and the tuber shape play an important role (Haase *et al.,* 2007).

This result is in agreement with the findings of Habtamu *et al.* (2016b) reported that the mean values of dry matter and specific gravity and moisture contents were ranged from 20.92 to 30.66% and 1.0534to 1.0967, respectively. Getachew *et al*. (2016) also reported that the mean value of tuber specific gravity and tuber dry matter contents were ranged from 1.07 to 1.13 and 66 to 78.9%, respectively. Challa (2018) reported that the mean values of dry matter content and specific gravity of tuber were ranged from 18.14 to 28.47% and 1.06 to 1.10 g/cm3, with mean value of 24.24% and 1.08, respectively.

Table 9: Mean performance of 12 potato cultivars for physically analyzed quality parameters at Debre Birhan in 2017

| Cultivar | Tuber dry matter % age | Tuber specific gravity | Numbers of eyes Per tuber | Geometric mean diameter |
|---|---|---|---|---|
| Alemaya 624 | $23.8^{a}$ | $1.095^{ab}$ | $7.3^{bcd}$ | $44.0^{ab}$ |
| Awash | $21.7^{bc}$ | $1.084^{bcde}$ | $9.7^{a}$ | $39.0^{bc}$ |
| Menagesh | $21.7^{bc}$ | $1.078^{de}$ | $8.0^{bc}$ | $37.0^{bc}$ |
| Gorebella | $23.1^{ab}$ | $1.082^{cde}$ | $5.7^{d}$ | $40.9^{bc}$ |
| Gera | $22.0^{b}$ | $1.096^{a}$ | $7.0^{bcd}$ | $37.7^{bc}$ |
| Shenkolla | $22.1^{b}$ | $1.084^{bcde}$ | $8.0^{bc}$ | $42.3^{ab}$ |
| Belete | $21.7^{bc}$ | $1.094^{ab}$ | $8.7^{ab}$ | $40.0^{bc}$ |
| Bubu | $24.1^{a}$ | $1.088^{abcd}$ | $7.3^{bcd}$ | $44.8^{ab}$ |
| Keydinich | $17.7^{d}$ | $1.064^{f}$ | $7.0^{bcd}$ | $26.7^{d}$ |
| Enatbeguada | $22.1^{b}$ | $1.085^{abcde}$ | $6.7^{cd}$ | $41.0^{bc}$ |
| Akime | $21.9^{bc}$ | $1.092^{abc}$ | $7.7^{bc}$ | $33.0^{cd}$ |
| Dinkey | $20.3^{c}$ | $1.076^{e}$ | $7.0^{bcd}$ | $50.5^{a}$ |
| Range | 17.7-24.1 | 1.096-1.064 | 5.4-9.5 | 26.7-50.5 |
| Mean | 21.9 | 1.085 | 7.5 | 39.7 |
| CV | 3.8 | 0.5 | 11.9 | 11.8 |
| Level of significance | ** | ** | ** | ** |

Means followed by the same letter within a column are not significantly different at the prescribed level of probability. ** =significant at 1%, * = significant at 5% and ns = non-significant at 1% and 5%.

### 4.2.5.Mean performances of cultivars for chemically analyzed quality parameters

The starch content plays very important roles in the quality of potato products and varies with potato cultivars. Potatoes with higher starch content are well suited for food use, processing or starch manufacture (Liu *et al*., 2003). Esendal (1990) suggested that starch content values should be assembled into four groups: the highest starch content (contents higher than 19.0%, mashing), high starch content (contents between 16.0 and 19.0%, roasting) intermediate starch content (contents between 13.0 and 15.9%, cooking or roasting), and low starch content (contents up to 12.0%, boiling). Keydinich had the minimum total starch content with values of 11.7% whereas Bubu had the maximum total starch content with values 17.5%. The mean value of the total starch content was 15.5% (Table 10).In general, potato varieties with a starch content of 13% and above are the most preferred for processed products (Kirkman, 2007). Thus, all the tested varieties except Keydinich, had total starch content of 13% and above indicating their fitness for processing.

The statistical analysis in phosphorus, mineral concentrations, total carotinoides and crude proteins indicated the presence of highly significant ($P < 0.001$) variation among the 12 cultivars (Table 10). The phosphorous concentration (%) also greatly varied from 0.62 % in cultivar Enatbeguaro to 1.28% in variety Belete with the overall mean values of all cultivars being 1.03%. From the eight released varieties, 4 (50%) and 2 (50%) of farmers' cultivar were characterized by lower phosphorous content than the grand mean value (Table 10). Varieties also displayed considerable variations in the Fe concentration. This ranged from 21.5 mg $kg^{-1}$in Bubu to 48 mg $kg^{-1}$ in Gera, with an overall mean value of 36 mg $kg^{-1}$. Similarly, Zn concentrations varied from 22.5 ppm to 48.5 ppm, with a mean value of 36.5 ppm. The lowest and the highest value of Zn were obtained from the farmer's cultivars. The lowest value was obtained from Enatbeguaro (22.5ppm) while the highest value was from Akime (48ppm) (Table 10). Iron and zinc bioavailability to humans depends on the overall composition of the diet (Andre *et al.,* 2007).

Similar to the mineral concentrations, varieties also showed highly significant differences in their total carotinoide and crude protein contents. Total carotinoide concentration values ranged from 20.7 to 27.4 µg $g^{-1}$. The lowest and the highest carotinoide concentrations were obtained from the farmer's cultivar Enatbeguaro and Keydinich, respectively (Table 10). In terms of protein concentration, the value ranged from 8.1% to 12.3%. Relatively higher protein concentration was found in variety Menagesh with values of 12.3%. The cultivar which had the lowest tuber protein concentration was variety Bubu (8.1%). The overall mean value for tuber protein concentration contents of all cultivars was 9.9%. The distribution of protein concentration values revealed that 75% of the farmers' cultivar and 37.5 % of released varieties had above average values. In summery farmers' varieties are superior to the released varieties only in iron (Fe) content (42.0 vs 33.1 mg/kg) among the chemical and physical quality parameters. The released varieties were significantly superior to the farmers' varieties in Starch content (15.8 vs 14.9%), in P (1.08 vs 0.94 units), in Zn (41.9 vs 25.7 mg/kg), and in Crude protein (10.1 vs 9.5%). but did not differ in total carotinoides (23 vs 23 µg/g). It was observed that cultivars with high specific gravity displayed higher percentage of dry matter content while low dry matter was observed in cultivars with low specific gravity (Table 10).

Accordingly, many authors reported that there is a wide range of variation among Potato cultivars for chemical and physical quality parameters. Wassu (2016) revealed that Belete variety had maximum dry matter percentage over three locations for three cropping seasons among 17 potato genotypes. In potato tubers the main dry matter components are carbohydrates, around 75% of the total dry matter. The largest portion of these carbohydrates is made up of starch (Camire *et al.*, 2009). Lemma, (2018) recorded starch content values ranging between 6.70% and 18.43% of dry weight at two locations. The mean values of dry matter content and specific gravity of tuber ranged from 18.14 to 28.47% and 1.06 to 1.10 g/cm3, with mean value of 24.24% and 1.08 g/cm3, respectively. Tesfaye *et al.* (2012) reported Fe, Zn, P and total protein concentration values that ranged from 5.12 to 266, 6.05 to 24.12 $mg.kg^{-1}$,49 to 469 $mg.kg^{-}1$ and 3.58 % to 7.94 %, respectively, among 21 released and widely grown farmers' potato varieties tested at two different locations. Similarly Bonierbale *et al.* (2011) reported Fe concentration ranging from 11.24 to 30.82 $mg.kg^{-1}$among 582 native Andean potato genotypes. Equally, Ekin (2011) revealed Fe and Zn concentrations of eight potato varieties that ranged from 75.03 to 122.69 and 15.21 to 18.96 $mg.kg-^{1}$, respectively. Andre *et al.* (2007) reported carotenoid content that ranged between 2.83 and 36.21 $\mu g\ g-^{1}$ on dry weight basis.

Table 10: Mean performance of 12 potato cultivars for chemically analyzed quality parameters at Debre Birhan in 2017

| Cultivar | Starch content (%) | Phosphorous % | Iron mg/kg | Zinc mg/Kg | Total Carotenoids µg/g | Crude Proteins %age |
|---|---|---|---|---|---|---|
| Alemaya 624 | $17.2^{a}$ | $1.23^{ab}$ | $23.3^{b}$ | $41.0^{ab}$ | $22.9^{bcde}$ | $10.6^{bc}$ |
| Awash | $15.4^{bc}$ | $0.91^{d}$ | $39.8^{a}$ | 23.8c | $21.3^{de}$ | $8.4^{f}$ |
| Menagesh | $15.4^{bc}$ | $1.01^{bcd}$ | $41.9^{a}$ | $40.5^{ab}$ | $22.9^{cde}$ | $12.3^{a}$ |
| Gorebella | $16.6^{ab}$ | $1.17^{abc}$ | $41.7^{a}$ | $25.0^{c}$ | $23.9^{bcde}$ | $9.2^{de}$ |
| Gera | $15.6^{b}$ | $1.17^{abc}$ | $48.0^{a}$ | $46.2^{a}$ | $24.4^{abcd}$ | $10.2^{c}$ |
| Shenkolla | $15.7^{b}$ | $0.98^{cd}$ | $25.4^{b}$ | $45.0^{a}$ | $24.8^{abc}$ | $8.7^{ef}$ |
| Belete | $15.3^{bc}$ | $1.28^{a}$ | $42.6^{a}$ | $44.0^{a}$ | $25.7^{ab}$ | $9.8^{cd}$ |
| Bubu | $17.5^{a}$ | $0.87^{d}$ | $21.5^{b}$ | $39{\cdot}0^{ab}$ | $21.6^{cde}$ | $8.11^{f}$ |
| Keydinich | $11.7^{d}$ | $1.03^{bcd}$ | $42.3^{a}$ | $31.4^{bc}$ | $27.4^{a}$ | $11.5^{ab}$ |
| Enatbeguada | $15.7^{b}$ | $0.62^{e}$ | $44.0^{a}$ | $22.5^{c}$ | $20.7^{e}$ | $8.7^{ef}$ |
| Akime | $15.4^{bc}$ | $1.1^{abcd}$ | $38.0^{a}$ | $48.5^{a}$ | $21.6^{cde}$ | $10.6^{bc}$ |
| Dinkey | $14.0^{c}$ | $0.94^{cd}$ | $24.4^{b}$ | $30.5^{bc}$ | $23.4^{bcde}$ | $10.4^{c}$ |
| Range | 11.7-17.5 | 0.62-1.28 | 21.5-48 | 22.5-48.5 | 20.7-27.4 | 8.1-12.3 |
| Mean | 15.5 | 1.03 | 36 | 36.5 | 23.3 | 9.9 |
| CV | 4.8 | 12.5 | 15.5 | 17.5 | 7.7 | 5.3 |
| Level of significance | ** | ** | ** | ** | ** | ** |

Means followed by the same letter within a column are not significantly different at the described level of probability. ** =significant at 1%, * = significant at 5% and ns = non significant at 1% and 5%.

## 4.3.Variability components

Estimates of different genetic parameters like phenotypic variances ($\sigma^2$p), genotypic variances ($\sigma^2$g), genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability (broad sense), genetic advance (GA) and genetic advance as percentage of mean (GA %) of twenty seven characters from twelve cultivars under study were estimated and results are presented in Table 11.

### 4.3.1.Estimates of phenotypic and genotypic variation

The phenotypic coefficients of variation (PCV) values were also higher than the corresponding genotypic coefficients of variation (GCV) values for all the characters. This indicates the apparent or observed variations in the genotypes for the trait were not only due to genotypic effect but also due to environmental influences (Haydar *et al*., 2009).Phenotypic and genotypic coefficient of variation ranged high for days to maturity and unmarketable tuber yield, respectively. The phenotypic and genotypic coefficient of variation values can be categorized as low (<10%), moderate (10-20%), and high (>20%) as indicated by Deshmuk *et al.,* (1986). Most of the characters had high phenotypic and genotypic coefficient of variation. The maximum phenotypic coefficient of variation was estimated for number of unmarketable tuber, unmarketable tuber yield ha$^{-1}$, marketable tuber yield ha$^{-1}$, number of marketable tuber, total tuber yield, number of total tuber, tuber number per hill, average tuber weight, zinc and iron. High PCV and GCV indicated that the traits are controlled by genetic factor and hence there is a higher chance of improvement of the crop through selection.

However, days of flowering, days to maturity, tuber dry matter content, specific gravity of tuber, starch content and total carotinoids had low PCV and GCV. It indicates the difficulty of improving these traits through phenotypic selection. There may also be some chance of improving traits with moderate GCV through phenotypic selection. Moderate phenotypic coefficient of variation was observed for plant height, large size tuber percentage, number of eyes per tuber, geometric mean diameter, phosphorous and crude proteins (Table 11).The traits which exhibited high estimates of PCV and GCV had high probability of improvement through selection while traits with low estimates of PCV and GCV are difficult or virtually impractical to improve through selection due to the masking effect of environment on the genotypic effect (Sing, 1990).

Our findings are in accordance with the findings by Mondal (2003) obtained high PCV and GCV for average tuber weight /plant, tuber yield/plant and tubers number/plant. Similar findings were reported by Haydar *et al*. (2009) where high genotypic coefficient of variability was recorded for average tuber weight Addisu *et al*. (2013) also reported high and moderate PCV and GCV values in potato germplasm they studied for number of tubers per plant, total tuber yield, tuber yield and number of stems per plant. But, days to maturity had lowest PCV and GCV, and hence this trait provides practically less chance for selection. Our results are also in accordance with result of Sattar *et al*. (2007) who reported low GCV and PCV for days to maturity. Baye *et al*. (2002**)** that reported high PCV and GCV for tuber weight per hill, marketable tuber yield and total tuber yield results are similar to our results but high PCV and GCV for days to 50% flowering  was differ from our result.

### 4.3.2.Estimation of broad sense heritability

In the present study, heritability estimate in broad sense was calculated for tuber yield, its components and tuber quality. Thus, estimate of heritability in broad sense ($h^2b$) was calculated for all the twenty seven characters studied. The estimated heritability ranged from 65.35 % to 97.53 % for days to maturity and marketable tuber yield $ha^{-1}$, respectively (Table 11).Accordingly, high estimates of heritability were found to be the most heritable traits in the potato cultivars studied. This indicates that selection for these traits in the cultivars would be most effective for the expression of these characters in the succeeding generations. Therefore, a good improvement can be made if some of these characters are considered as selection criteria in future breeding program. On the other hand, however, low heritability and moderate heritability was not observed in the study characters. This high heritability showed that there was low influence of environmental fluctuations on the characters and that the characters were governed by genetic factors. Hence, selection for these characters will lead to the identification of desirable cultivars.

The present findings are in accordance with findings reported by Panigrahi *et al*. (2017) reported high heritability for plant height, dry matter content, marketable and total tuber yields. Sattar *et al*. (2007) recorded for plant height and average weight of a tuber. Addisu *et al*., (2013) also reported moderate to high heritability values for tuber diameter, days to 50% flowering and plant height. Tripura *et al.* (2016)for average tuber number per hill, average tuber weight and total tuber yield reported both high heritability and genetic advance as percent mean. Chala, (2018) reported high heritability coupled with high genetic advances was in total tuber yield, marketable, unmarketable tuber yield, plant height, average stem number, average tuber number per hill, average tuber weight, dry matter content, proportion of larger tuber size distributions, iron and zinc.

### 4.3.3.Genetic advance and genetic advance as percent of mean

Based on the estimates of heritability (broad sense) phenotypic standard deviation and selection intensity at 5% probability level expected genetic advance in 27 potato traits was computed and is presented in Table 11.

In the present study high estimates of genetic advance as percentage of mean were obtained for characters such as number of unmarketable tubers), unmarketable tuber yield $ha^{-1}$, marketable tuber yield $ha^{-1,}$ average tuber weight, iron content andzinc content. The high value of genetic advance as percentage of mean for these traits showed that these characters are governed by additive genes and selection will be rewarding for the further improvement of such characters. Moderate genetic advance as percentage of mean (10 to 20%) was observed in characters such as days of flowering. total carotinoids, starch content and tuber dry matter content. This suggests that both additive and non-additive gene action is operating in these characters. However, low genetic advance as per cent of the mean was observed in the characters such as, days to maturity and specific gravity of tuber (1.63 %). In the present investigation, high heritability estimates coupled with high genetic advance directional selection for these traits in genetically diverse material could be effective for desired genetic improvement. In agreement with the above results, similar findings were also supported by Baye *et al*. (2002) and Addisu *et al*, (2013) reported moderate genetic advance as percent of the mean for plant height and average tuber weight. Haydar *et al*. (2009) who reported high heritability (in a broad sense) as well as high genetic advance as percentage of mean for plant height, tubers number and tuber yield.

Table 11: Estimate of variability components for 27 characters in 12 potato cultivars evaluated at Debre Birhan in 2017

| Characters | Grand Mean | $\sigma^2$e | $\sigma^2$g | $\sigma^2$p | GCV (%) | PCV (%) | $H^2$ (%) | GA | GAM (%) |
|---|---|---|---|---|---|---|---|---|---|
| DF | 72.5 | 10.0 | 48.77 | 52.10 | 9.63 | 9.96 | 93.60 | 14.41 | 19.87 |
| DM | 117.7 | 35.9 | 22.57 | 34.53 | 4.04 | 4.99 | 65.35 | 9.80 | 8.33 |
| PH | 49.8 | 26.2 | 73.60 | 82.33 | 17.23 | 18.22 | 89.39 | 17.70 | 35.54 |
| TNH | 10.6 | 2.1 | 8.30 | 9.00 | 27.18 | 28.30 | 92.22 | 5.94 | 56.07 |
| ATW | 58 | 41.3 | 249.90 | 263.67 | 27.26 | 28.00 | 94.78 | 32.61 | 56.23 |
| MTY | 23.55 | 3.7 | 48.63 | 49.87 | 29.61 | 29.99 | 97.53 | 14.39 | 61.09 |
| NMT | 314 | 709.5 | 6721.83 | 6958.33 | 26.11 | 26.57 | 96.60 | 169.14 | 53.87 |
| UMTY | 1.99 | 0.8 | 2.73 | 3.00 | 83.08 | 87.04 | 91.11 | 3.41 | 171.39 |
| NUMT | 153 | 4420 | 18524.33 | 19997.67 | 88.96 | 92.43 | 92.63 | 280.78 | 183.52 |
| TTY | 23.53 | 3.7 | 37.23 | 38.47 | 25.93 | 26.36 | 96.79 | 12.59 | 53.50 |
| NTT | 467 | 4987 | 15746.00 | 17408.33 | 26.87 | 28.25 | 90.45 | 258.87 | 55.43 |
| LTY | 17.65 | 3.9 | 35.70 | 37.00 | 33.85 | 34.46 | 96.49 | 12.33 | 69.84 |
| LST | 68.1 | 24 | 126.67 | 134.67 | 16.53 | 17.04 | 94.06 | 23.22 | 34.09 |
| MTY's | 4.77 | 0.95 | 2.75 | 3.07 | 34.77 | 36.71 | 89.67 | 3.42 | 71.72 |
| MSY | 18.6 | 13.8 | 29.40 | 34.00 | 29.15 | 31.35 | 86.47 | 11.19 | 60.14 |
| STY | 3.11 | 1 | 2.80 | 3.13 | 53.80 | 56.92 | 89.36 | 3.45 | 111.00 |
| SST | 13.2 | 11.8 | 93.40 | 97.33 | 73.21 | 74.74 | 95.96 | 19.94 | 151.04 |
| TDM | 21.9 | 0.7 | 2.53 | 2.77 | 7.27 | 7.60 | 91.57 | 3.28 | 14.99 |
| SGT | 1.085 | 0.00003 | 0.00 | 0.00 | 0.79 | 0.84 | 88.00 | 0.02 | 1.63 |
| NEP | 7.5 | 0.8 | 0.77 | 1.03 | 11.67 | 13.55 | 74.19 | 1.81 | 24.08 |
| GMD | 39.7 | 22 | 28.83 | 36.17 | 13.53 | 15.15 | 79.72 | 11.08 | 27.90 |
| SC | 15.5 | 0.6 | 2.00 | 2.20 | 9.12 | 9.57 | 90.91 | 2.92 | 18.82 |
| P | 1.03 | 0.017 | 0.03 | 0.03 | 16.05 | 17.64 | 82.83 | 0.34 | 33.11 |
| Fe | 36.1 | 31 | 80.33 | 90.67 | 24.83 | 26.38 | 88.60 | 18.49 | 51.22 |
| Z | 36.5 | 40.7 | 73.77 | 87.33 | 23.53 | 25.60 | 84.47 | 17.72 | 48.54 |
| TC | 23.3 | 3.2 | 2.97 | 4.03 | 7.39 | 8.62 | 73.55 | 3.55 | 15.25 |
| CP | 9.9 | 0.27 | 1.61 | 1.70 | 12.82 | 13.17 | 94.71 | 2.62 | 26.44 |

DF=Days to 50% flowering, DM=Days to maturity, PH=Plant height (cm), TNH=Average tuber number per hill, ATW=Average tuber weight (g/tuber), MTY=Marketable tuber yield (t $ha^{-1}$), NMT=Number of marketable tuber $ha^{-1}$ (in 1000 base), UMTY=Unmarketable tuber yield (t $ha^{-1}$), NUMT=Number of unmarketable tuber $ha^{-1}$ (in 1000 base), TTY=Total tuber yield (t $ha^{-1}$), NTT=Number of total tuber $ha^{-1}$ (in 1000 base), LTY=Large tuber yield (t $ha^{-1}$), LST=Large size tubers (%), MTY's=Medium tuber yield (t $ha^{-1}$), MST=Medium size tubers (%), STY=Small tuber yield (t $ha^{-1}$), SST=Small size tubers (%), TDM=Dry matter content (%), SGT=Specific gravity of tubers ($gcm^{-3}$), NEP=numbers of eyes per tuber, GMD=Geometric mean diameter ($mm^3$), SC=Starch content (g/100g), P=Phosphorous(%) age, Fe=Iron mg/kg, Z=Zinc (%) age, TC=Total Carotenoids and CP=Crude Protein (%) age.

## 4.4. Association of Characters

### 4.4.1. Correlation analysis

The estimates of genotypic and phenotypic correlation coefficients between total tuber yield with all possible pairs of yield components and qualitative characters of potato cultivars are presented in Table 12. Results of this analysis indicated that genotypic correlation coefficient ($r_g$) in general were higher in magnitude than the corresponding phenotypic correlation coefficients ($r_p$) for almost all pairs of characters. This revealed that association among these characters was under genetic control indicating the preponderance of genetic variance and lower influence of environmental factors in determining the association between the traits. Total tuber yield $ha^{-1}$ was positively correlated with geometric mean diameter, starch content, and zinc content but negatively correlated with small size tuber percentage, iron and crude protein at both phenotypic and genotypic levels. A selection program designed to improve total tuber yield $ha^{-1}$ is expected to also improve geometric mean diameter, starch and zinc content but may lead to the reduction of small size tuber percentage, iron content and crude protein. Simultaneous improvement of tuber yield and the quality traits iron and crude protein content appears to be a difficult task due the negative correlation of these quality traits with tuber yield. But there is no correlation between total tuber yield $ha^{-1}$ and phosphorous, medium size tuber percentage and total carotenoids. Tuber yield can be improved independently from phosphorous content, medium size tuber percentage and the amount of total carotenoids in the tuber. Presence of negative correlation indicated that the traits are associated in opposite direction and selection of genotypes for high performance of one trait leads to the reduction of performance in the other trait.

It is important to give attention to phenology of the crops in the process of the selection of potato genotypes for high tuber yield (Ebrahim, 2018). The presence of significant positive correlation of phenology traits with total tuber yield per hectare. Phenotypic correlation ($r_p$) measures the extent to which the two observed characters are linearly related while genotypic correlation ($r_g$) measures the extent to which degree, to which the same genes or closely linked genes cause co-variation (simultaneous variations) in two different characters (Falconer and Mackay, 1996). Under such state selection of tall potato cultivars with high amount of marketable tuber yield ha$^{-1}$will, and higher in starch content guarantee the selection of better performing genotype with better total tuber yield ha$^{-1}$.

Plant height had positive and significant genotypic and phenotypic associations with average tuber weight and marketable tuber yield ha$^{-1}$. But it was significantly and negatively correlated with unmarketable tuber yield ha$^{-1}$ and small tuber size percentage at phenotypic level. Tuber number per hill had positive and highly significant genotypic associations with unmarketable tuber yield ha$^{-1}$ and percentage of small tuber size. Phenotypically, it had positive and highly significant correlation with unmarketable tuber yield ha$^{-1}$and small size tuber percentage. Tuber number per hill had highly significant but negative association with average tuber weight, large size tuber percentage and geometric mean diameter at phenotypic and genotypic levels. At phenotypic and genotypic level, plant height, marketable yield ha$^{-1}$, total tuber yield ha$^{-}$, large size tuber percentage, geometric mean diameter and starch content were observed to have positive and highly significant correlations with average tuber weight. Average tuber weight had highly significant but negative correlation with tuber number per hill, unmarketable tuber yield ha$^{-1}$ and small size tuber percentage both at genotypic and phenotypic level.

Marketable tuber yield $ha^{-1}$ had highly significant and positive correlation both at genotypic and phenotypic level with average tuber weight, large size tuber weight, geometric mean diameter and starch content. Marketable tuber yield $ha^{-1}$ exhibited highly significant but negative correlation at phenotypic level with unmarketable tuber yield $ha^{-1}$ and Small size tuber percentage. Small size tuber percentage was positively and highly significantly correlated with unmarketable tuber yield $ha^{-1}$ at genotypic and phenotypic level. Unmarketable tuber yield $ha^{-1}$ had highly significant but negative correlation with large size tuber percentage, geometric mean diameter and starch content at genotypic and phenotypic level. At phenotypic level large tuber size percentage was highly significantly and positively correlated with plant height and marketable tuber yield $ha^{-1}$.This results agreed with the findings ofAddisu *et al.* (2013) and Sattar *et al.* (2007) who also reported positive correlation of total tuber yield with big tuber percentage at both phenotypic and genotypic level. Ebrahim (2018), also showed positive and highly significant ($P<0.01$) correlation of total tuber yield with average tuber weight, marketable tuber yield and large size tubers both at the genotypic and phenotypic levels. Tripura *et al*. (2016) reported positive and significant association of tuber number with total tuber yield. Khayatnezhad *et al*. (2011) indicated that average tuber weight and tubers/plant were the main components of tuber yield.

Table 12:Estimation of genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficient for 16characters in 12 potato cultivars tested at Debre Birhan in 2017

| **Char** | **PH** | **TNH** | **ATW** | **MY** | **UMY** | **TTY** | **LST** | **MST** | **SST** | **GMD** | **SC** | **P** | **Fe** | **Zn** | **TC** | **CP** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PH** | 1 | -0.184 | 0.594 | 0.694 | -0.496 | 0.652 | 0.513 | -0.084 | -0.549 | 0.365 | 0.648 | -0.407 | -0.138 | -0.11 | -0.441 | -0.412 |
| **TNH** | -0.158 | 1 | -0.734 | -0.09 | 0.821 | 0.127 | -0.773 | 0.292 | 0.728 | -0.65 | -0.231 | 0.262 | 0.036 | 0.294 | 0.45 | 0.04 |
| **ATW** | 0.542 | -0.704 | 1 | 0.692 | -0.868 | 0.545 | 0.913 | -0.34 | -0.856 | 0.606 | 0.575 | -0.22 | -0.056 | -0.03 | -0.376 | -0.304 |
| **MY** | 0.653 | -0.034 | 0.659 | 1 | -0.587 | 0.974 | 0.567 | 0.035 | -0.68 | 0.418 | 0.779 | 0.031 | -0.17 | 0.209 | -0.147 | -0.611 |
| **UMY** | -0.42 | 0.827 | -0.829 | -0.505 | 1 | -0.389 | -0.879 | 0.072 | 0.987 | -0.818 | -0.675 | 0.137 | 0.199 | 0.112 | 0.476 | 0.426 |
| **TTY** | 0.606 | 0.203 | 0.492 | 0.968 | -0.271 | 1 | 0.4 | 0.06 | -0.498 | 0.247 | 0.698 | 0.074 | -0.138 | 0.27 | -0.034 | -0.577 |
| **LST** | 0.451 | -0.718 | 0.883 | 0.528 | -0.844 | 0.342 | 1 | -0.521 | -0.858 | 0.762 | 0.627 | -0.12 | -0.308 | 0.119 | -0.447 | -0.191 |
| **MST** | -0.076 | 0.213 | -0.323 | 0.018 | 0.075 | 0.042 | -0.547 | 1 | 0.009 | -0.149 | -0.01 | 0.034 | 0.26 | -0.332 | 0.144 | -0.467 |
| **SST** | -0.488 | 0.716 | -0.838 | -0.636 | 0.96 | -0.429 | -0.84 | 0.007 | 1 | -0.81 | -0.737 | 0.113 | 0.216 | 0.059 | 0.444 | 0.5 |
| **GMD** | 0.212 | -0.48 | 0.471 | 0.364 | -0.641 | 0.219 | 0.599 | -0.059 | -0.683 | 1 | 0.551 | -0.169 | -0.639 | -0.122 | -0.347 | -0.451 |
| **SC** | 0.473 | -0.201 | 0.524 | 0.671 | -0.583 | 0.577 | 0.606 | -0.111 | -0.663 | 0.421 | 1 | 0.057 | -0.346 | 0.179 | -0.572 | -0.492 |
| **P** | -0.298 | 0.128 | -0.134 | 0.044 | 0.042 | 0.062 | -0.044 | 0.003 | 0.049 | -0.167 | 0.053 | 1 | 0.088 | 0.551 | 0.535 | 0.395 |
| **Fe** | -0.079 | 0.048 | -0.093 | -0.159 | 0.217 | -0.114 | -0.321 | 0.29 | 0.211 | -0.409 | -0.343 | -0.018 | 1 | -0.162 | 0.142 | 0.247 |
| **Zn** | -0.027 | 0.236 | -0.02 | 0.182 | 0.086 | 0.229 | 0.081 | -0.251 | 0.066 | -0.057 | 0.102 | 0.349 | -0.047 | 1 | 0.21 | 0.305 |
| **TC** | -0.279 | 0.374 | -0.305 | -0.063 | 0.411 | 0.05 | -0.386 | 0.19 | 0.353 | -0.165 | -0.518 | 0.389 | 0.225 | 0.253 | 1 | 0.302 |
| **CP** | -0.38 | 0.023 | -0.263 | -0.563 | 0.335 | -0.529 | -0.14 | -0.426 | 0.439 | -0.326 | -0.425 | 0.316 | 0.203 | 0.274 | 0.259 | 1 |

PH=Plant height (cm), TNH=Average tuber number per hill, ATW=Average tuber weight (g/tuber), MY=Marketable tuber yield (t $ha^{-1}$), UMY=Unmarketable tuber yield (t $ha^{-1}$), TTY=Total tuber yield (t $ha^{-1}$), LST=Large size tubers (%),MST=Medium size tubers (%),SST=Small size tubers (%), GMD=Geometric mean diameter ($mm^3$), SC=Starch content (g/100g), P=Phosphorous, Fe=Iron mg/kg, Z=Zinc, TC=Total Carotinoidsand CP=Crude Protein.

### 4.4.2.Path coefficient analysis

In the present study, total tuber yield ha$^{-1}$of potato was considered as effect dependent on fifteen independent variables, which were considered as causes. Genotypic correlation coefficient of various characters of total tuber yield ha$^{-1}$ was further partitioned into their direct and indirect effects. The estimates of genotypic direct and indirect effects of these characters on total tuber yield ha$^{-1}$are presented in Table 13. Average tuber weight, cruide protein, unmarketable tuber yield ha$^{-1}$ small size tuber percentage, total carotinoids, zinc, plant height and geometric mean diameter had positive direct effect on total tuber yield ha$^{-1}$. Lenka and Mishra (1973) suggested five categories of direct and indirect effects based on range of values negligible (0.00-0.09), low (0.10-0.19), moderate (0.20-0.29), high (0.30-1.00) and very high (>1.00).

On genotypic level the highest significant positive direct effect on total tuber yield ha$^{-1}$ was contributed by average tuber weight, starch content and unmarketable tuber yield. This suggested that those characters are good contributor to increase total tuber yield ha$^{-1}$ and selection of cultivars with highest values for those traits leads to the increment of tuber yield.On the other hand, negative direct effects on total tuber yield ha$^{-1}$ were exerted by marketable tuber yield ha$^{-1}$, large size tubers percentage and crude protein. Indicating that selection in favor of genotypes with high mean values for these three traits will lead to the reduction of total tuber yield. Tuber number per hill and medium size tubers percentage had negligible positive and negative correlation with total tuber yield, respectively. Khayatnez had *et al*. (2011) who reported that plant height and tuber weight per plant had highest direct effect on tuber yield. This is also in agreement with the current findings. He also reported that small tuber percentage had negative low direct effect on tuber yield, which disagree with this finding. The large positive genotypic correlation between total tuber yield ha$^{-1}$and starch content is the results of the large positive indirect effect of marketable tuber yield ha$^{-1}$, plant height and average tuber weight.

Medium tuber size percentage and tuber number per hill exerted negligible negative and positive direct effect to total tuber yield ha$^{-1}$, respectively. It also recorded a positive very high and high indirect effect on total tuber yield ha$^{-1}$ through average tuber weight, unmarketable tuber yield ha$^{-1}$, large tuber size percentage and starch content, other characters doesn't show positively very high and high indirect effect on total tuber yield ha$^{-1}$. But it observed moderate indirect positive effect for total tuber yield ha$^{-1}$through zinc, total carotinoids and crude protein(Table 13). Therefore, it is evident from the results of the study high consideration should be given for average tuber weight, marketable tuber yield ha$^{-1}$, unmarketable tuber yield ha$^{-1}$, small size tubers percentage and starch content with emphasis on total tuber yield ha$^{-1}$. This finding agree with that of (Sattar et al., 2007), who reported that plant height and average weight of tuber had high positive direct effect on tuber yield indicating their importance in selection for yield improvement. Similarly Addisu *et al.*, (2013) reported path analyses of total tuber yield and its component demonstrated that had the highest correlation with tuber yield. Abraham *et al.* (2014) who reported that plant height had positive and low direct effect on tuber yield. Whereas, proportion of larger tuber sizes exerted high negative direct effects on tuber yield. But he also reported that small tuber percentage and medium tuber showed Strong negative direct effect on tuber yield, which is not in line with this study. Haydar *et al*., 2009) reported similar result to his study in plant height and number of tubers/plant that had high and direct contribution towards tuber yield/plant and could be considered as selection criteria in potato breeding program. Addisu *et al*. (2013) reported that plant height had positive direct effect on yield, But he also reported that number of stem per plant showed negative direct effect on potato germplasm, which is agreed with this study. On the other hand, Getachew and Wassu (2016) rerecorded marketable tuber yield had positive direct effect at genotypic and phenotypic level on total tuber yield, this result differ from this result.

The Residual of the analysis at genotypic level was0.3 percent that implies the parameters considered in this study explained 99.7 percent of total tuber yield and the remaining 0.3 percent is expressed by other parameters not considered in this study. This further explained the parameters chosen for the studies were good in explaining the observed total tuber yield variations.

The results of path analysis at phenotypic level are presented in Table 14. Phenotypic path coefficient analysis results revealed that marketable tuber yield $ha^{-1}$ (1.114) followed by unmarketable tuber yield $ha^{-1}$ (0.291) had exerted maximum positive direct effect on total tuber yield $ha^{-1}$ (Table 14). Large size tubers percentage, small size tubers percentage, medium size tubers percentage, average tuber number per hill and average tuber weight had exerted low positive direct effect with total tuber yield $ha^{-1}$. Marketable tuber yield $ha^{-1}$ had high positive indirect effect through average tuber weight, plant height and large size tubers (%). Marketable tuber yield $ha^{-1}$ had exerted low negative direct effect with unmarketable tuber yield, small size tubers (%) had exerted high negative indirect effect on marketable yield. plant height had negligible negative direct effect on total tuber yield $ha^{-1}$ Table 14.

Table 13: Estimates of direct (bold and diagonal) and indirect effect (off-diagonal) of different characters on total tuber yield at genotypic level in potato cultivars tested at Debre Birhan in 2017

| Chara | PH | TNH | ATW | MY | UMY | LST | MST | SST | GMD | SC | P | Fe | Zn | TC | CP | TTY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PH** | **0.275** | -0.013 | 0.803 | -0.249 | -0.255 | -0.274 | 0.0010 | -0.194 | 0.073 | 0.538 | -0.0384 | -0.0142 | -0.032 | -0.203 | 0.235 | 0.652 |
| **TNH** | -0.051 | **0.073** | -0.992 | 0.032 | 0.422 | 0.413 | -0.0034 | 0.258 | -0.131 | -0.192 | 0.0247 | 0.0037 | 0.086 | 0.207 | -0.023 | 0.127 |
| **ATW** | 0.163 | -0.054 | **1.351** | -0.248 | -0.446 | -0.488 | 0.0040 | -0.303 | 0.122 | 0.478 | -0.0207 | -0.0058 | -0.009 | -0.173 | 0.173 | 0.545 |
| **MY** | 0.191 | -0.007 | 0.935 | **-0.358** | -0.302 | -0.303 | -0.0004 | -0.241 | 0.084 | 0.648 | 0.0029 | -0.0174 | 0.061 | -0.068 | 0.348 | 0.974 |
| **UMY** | -0.136 | 0.060 | -1.173 | 0.210 | **0.514** | 0.470 | -0.0009 | 0.349 | -0.165 | -0.561 | 0.0130 | 0.0204 | 0.033 | 0.219 | -0.242 | -0.389 |
| **LST** | 0.141 | -0.056 | 1.233 | -0.203 | -0.452 | **-0.535** | 0.0062 | -0.304 | 0.153 | 0.521 | -0.0113 | -0.0315 | 0.035 | -0.206 | 0.109 | 0.400 |
| **MST** | -0.023 | 0.021 | -0.459 | -0.012 | 0.037 | 0.279 | **-0.0118** | 0.003 | -0.030 | -0.008 | 0.0032 | 0.0267 | -0.097 | 0.066 | 0.266 | 0.060 |
| **SST** | -0.151 | 0.053 | -1.157 | 0.243 | 0.507 | 0.459 | -0.0001 | **0.354** | -0.163 | -0.612 | 0.0106 | 0.0221 | 0.017 | 0.204 | -0.285 | -0.498 |
| **GMD** | 0.100 | -0.047 | 0.819 | -0.150 | -0.421 | -0.408 | 0.0018 | -0.287 | **0.201** | 0.458 | -0.0160 | -0.0654 | -0.036 | -0.160 | 0.257 | 0.247 |
| **SC** | 0.178 | -0.017 | 0.777 | -0.279 | -0.347 | -0.335 | 0.0001 | -0.261 | 0.111 | **0.831** | 0.0054 | -0.0354 | 0.053 | -0.263 | 0.280 | 0.698 |
| **P** | -0.112 | 0.019 | -0.297 | -0.011 | 0.071 | 0.064 | -0.0004 | 0.040 | -0.034 | 0.048 | **0.0943** | 0.0090 | 0.162 | 0.246 | -0.225 | 0.074 |
| **Fe** | -0.038 | 0.003 | -0.076 | 0.061 | 0.103 | 0.165 | -0.0031 | 0.076 | -0.128 | -0.287 | 0.0083 | **0.1024** | -0.048 | 0.065 | -0.141 | -0.138 |
| **Zn** | -0.030 | 0.021 | -0.041 | -0.075 | 0.058 | -0.063 | 0.0039 | 0.021 | -0.025 | 0.149 | 0.0520 | -0.0166 | **0.293** | 0.096 | -0.174 | 0.270 |
| **TC** | -0.121 | 0.033 | -0.507 | 0.053 | 0.245 | 0.239 | -0.0017 | 0.157 | -0.070 | -0.475 | 0.0505 | 0.0145 | 0.061 | **0.460** | -0.172 | -0.034 |
| **CP** | -0.113 | 0.003 | -0.411 | 0.219 | 0.219 | 0.102 | 0.0055 | 0.177 | -0.091 | -0.409 | 0.0373 | 0.0253 | 0.089 | 0.139 | **-0.569** | -0.577 |

PH=Plant height (cm), TNH=Average tuber number per hill, ATW=Average tuber weight (g/tuber), MTY=Marketable tuber yield (t $ha^{-1}$), UMTY=Unmarketable tuber yield (t $ha^{-1}$), TTY=Total tuber yield (t $ha^{-1}$), LST=Large size tubers (%),MST=Medium size tubers (%),SST=Small size tubers (%), GMD=Geometric mean diameter ($mm^3$), SC=Starch content (g/100g), P=Phosphorous, Fe=Iron mg/kg, Z=Zinc, TC=Total Carotenoids and CP=Crude Protein.

**Residual =0.003**

Table 14: Estimates of direct (bold and diagonal) and indirect effect (off-diagonal) of different characters on total tuber yield at phenotypic level in potato cultivars tested at Debre Birhan in 2017

| Charac | PH | TNH | ATW | MY | UMY | LST | MSTs | SST | GMD | SC | P | Fe | Zn | TC | CP | **TTY** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PH | **0.018** | -0.020 | 0.067 | 72.765 | -12.265 | 0.392 | -0.037 | -0.351 | 0.008 | -0.008 | -0.014 | 0.001 | 0.000006 | 0.006 | 0.0103 | 0.652 |
| TNH | -0.003 | **0.128** | -0.087 | -3.817 | 24.148 | -0.624 | 0.102 | 0.515 | -0.018 | 0.003 | 0.006 | -0.001 | -0.000048 | -0.008 | -0.0006 | 0.127 |
| ATW | 0.010 | -0.090 | **0.123** | 73.362 | -24.214 | 0.766 | -0.155 | -0.603 | 0.017 | -0.009 | -0.006 | 0.001 | 0.000004 | 0.007 | 0.0071 | 0.545 |
| MY | 0.011 | -0.004 | 0.081 | **111.389** | -14.741 | 0.458 | 0.008 | -0.458 | 0.013 | -0.011 | 0.002 | 0.002 | -0.000037 | 0.001 | 0.0153 | 0.974 |
| UMY | -0.007 | 0.106 | -0.102 | -56.247 | **29.192** | -0.733 | 0.036 | 0.691 | -0.024 | 0.010 | 0.002 | -0.003 | -0.000018 | -0.009 | -0.0091 | -0.389 |
| LST | 0.008 | -0.092 | 0.109 | 58.772 | -24.628 | **0.868** | -0.263 | -0.605 | 0.022 | -0.010 | -0.002 | 0.005 | -0.000017 | 0.009 | 0.0038 | 0.400 |
| MSTs | -0.001 | 0.027 | -0.040 | 1.967 | 2.203 | -0.475 | **0.480** | 0.005 | -0.002 | 0.002 | 0.000 | -0.004 | 0.000051 | -0.004 | 0.0116 | 0.060 |
| SST | -0.009 | 0.091 | -0.103 | -70.826 | 28.021 | -0.729 | 0.003 | **0.720** | -0.025 | 0.011 | 0.002 | -0.003 | -0.000014 | -0.008 | -0.0119 | -0.498 |
| GMD | 0.004 | -0.061 | 0.058 | 40.558 | -18.698 | 0.520 | -0.028 | -0.492 | **0.037** | -0.007 | -0.008 | 0.006 | 0.000012 | 0.004 | 0.0089 | 0.247 |
| SC | 0.008 | -0.026 | 0.065 | 74.694 | -17.018 | 0.526 | -0.053 | -0.477 | 0.016 | **-0.017** | 0.003 | 0.005 | -0.000021 | 0.011 | 0.0115 | 0.698 |
| P | -0.005 | 0.016 | -0.016 | 4.945 | 1.217 | -0.038 | 0.002 | 0.036 | -0.006 | -0.001 | **0.047** | 0.000 | -0.000071 | -0.009 | -0.0086 | 0.074 |
| Fe | -0.001 | 0.006 | -0.011 | -17.668 | 6.321 | -0.278 | 0.139 | 0.152 | -0.015 | 0.006 | -0.001 | **-0.015** | 0.000010 | -0.005 | -0.0055 | -0.138 |
| Zn | 0.000 | 0.030 | -0.003 | 20.317 | 2.522 | 0.071 | -0.121 | 0.048 | -0.002 | -0.002 | 0.016 | 0.001 | **-0.000204** | -0.006 | -0.0074 | 0.270 |
| TC | -0.005 | 0.048 | -0.038 | -7.031 | 11.997 | -0.336 | 0.091 | 0.254 | -0.006 | 0.009 | 0.018 | -0.003 | -0.000052 | **-0.022** | -0.0070 | -0.034 |
| CP | -0.007 | 0.003 | -0.032 | -62.668 | 9.791 | -0.121 | -0.205 | 0.316 | -0.012 | 0.007 | 0.015 | -0.003 | -0.000056 | -0.006 | **-0.0272** | -0.577 |

All variables were multiplied by $10^{-2}$

PH= plant height, TNH=tuber number per hill, ATW=average tuber weight, MY=marketable yield $ha^{-1}$, UMY=Unmarketable yield $ha^{-1}$, LST= large size tuber percentage, MSTs=mediumsize tuber percentage, SST=smallsize tuber percentage,GMD=geometric mean diameter, SG=Specific gravity, P=Phosphorous %age, Fe=Iron mg/kg, Zn=zinc mg/Kg, TC=Total Carotinoids µg/g , CP= Crude Proteins %age.

### 4.4.3.Cluster analysis

Cluster analysis classifies a set of observations into two or more mutually exclusive unknown groups based on combinations of interval variables. In this agglomerative hierarchical clustering technique was followed. Cluster analysis based on the average values of the 27 studied characters resulted in the grouping of the 12 potato cultivars in to five major clusters. The Mahalanobis distances $D^2$ (Inter and intra cluster) value based on the mean of the cultivars were computed for all possible pairs of clusters as shown in Table 15.

As the cluster analysis showed the maximum number of cultivars was in the Cluster I and Cluster V, each cluster consisted of 3 cultivars. The other three clusters contain two cultivars in each cluster. In cluster IV and cluster V both released varieties and Farmer's Cultivars were grouped under the same cluster.The resulting clusters of individuals should then exhibit high internal (within cluster) homogeneity and high external (between clusters) heterogeneity. Thus, if the classification is successful, individuals within a cluster shall be closer when plotted geometrically and different clusters shall be farther apart (Hair *et al.*, 1995).

Table 15: Clustering of potato cultivars based on Ward's method using squared Euclidean distance classified 12 cultivars tested at Debre Birhan in 2017

| Cluster | No of cultivars | Percentage | Name of cultivar |
|---|---|---|---|
| I | 3 | 25 | Belete, Bubu & Gorebella |
| II | 2 | 16.66 | Shenkolla& Alemaya 624 |
| III | 2 | 16.66 | Keydinich & Akime |
| IV | 2 | 16.66 | Menagesh & Dinkey |
| V | 3 | 25 | Enat Beguaro, Gera& Awash |

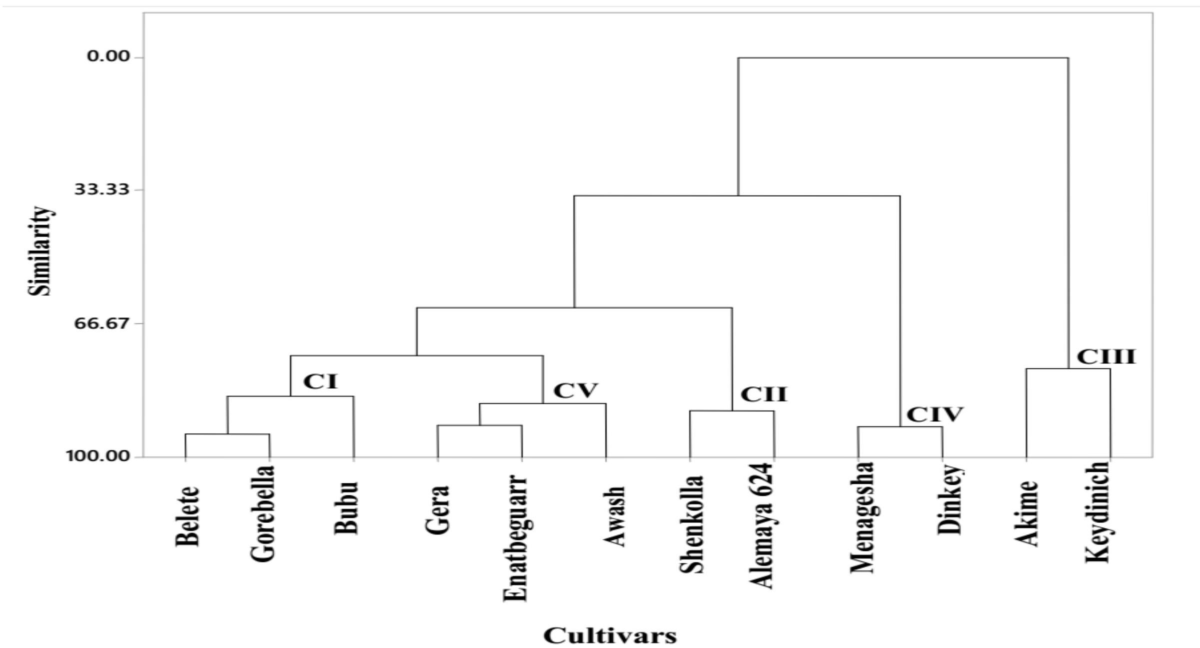



Figure 1: Dendrogram based on Euclidean distance Coefficient of 12 potato cultivars yield and quality traits

### 4.4.4.Cluster means analysis

All clusters were also noted to have variability in the respective clusters mean analysis values for all 27 tuber yield, yield components and quality related characters showed variability among cultivars presented in Table 16. The component of cluster mean for the days to 50% flower was highest in cluster-III which was followed by cluster –V and early flowering day was observed in cluster-I. Regarding days to maturity, cluster-V possesses the lately matured cultivars and the lowest days required to reach days to maturity was recorded from Cultivars that fall in cluster-II. The highest plant height was produced by the cultivars under cluster-I and the shortest average performance were observed in cluster-III. The component of cluster mean for tuber number per hill was recorded in cultivars in cluster-III and cluster-IV exhibits minimum numbers of tuber number per hill. The highest mean for Average tuber weight was observed in cluster-I and cluster-IV which was followed by cluster-V and the lowest weightwas observed in cluster-III. Number of marketable tubers $ha^{-1}$ showed the highest mean performance in cluster-II and the lowest mean values of this trait was showed by cultivars in cluster-IV. The character Number of unmarketable tubers $ha^{-1}$ andnumber of total tuber $ha^{-1}$ exhibited highest cluster mean for cluster-III but for both characters the small number was observed in cluster-IV. The highest cluster mean for marketable yield $ha^{-1}$ was recorded in cluster-I and for lowest in cluster-III. The highest cluster mean for unmarketable yield $ha^{-1}$ was observed in cluster-III and for lowest exhibited in cluster-IV. As regards total tuber yield $ha^{-1}$, the highest cluster mean was observed in cluster-I and the lowest for cluster-IV.

Large tuber size percentage and yield $ha^{-1}$ exhibited the highest mean performance in cluster-IV and cluster-I but the lowest found in cluster-III in both characters, respectively. The highest medium tuber yield $ha^{-1}$ was found in cluster-II and the lowest were observed in cluster-IV. Medium tuber size percentage showed highest mean performance in cluster-V where as for lowest in cluster-IV. The highest small tuber size percentage and yield $ha^{-1}$ was observed in cluster-III but was the lowest in cluster-I and IV, respectively. The highest mean for tuber dry matter was observed in cluster-I and the lowest was in cluster-III. The highest specific gravity was observed in cluster-II but cluster-IV showed the lowest mean performance. The highest number of eyes per tuber was observed in cluster-II and lowest was observed in cluster-I. Geometric mean diameter and starch content were exhibited the highest mean performance in cluster-IV and cluster-I, respectively, but the lowest performance in both character was in cluster-III. Phosphorous content in per cent showed highest mean performance in cluster-I and cluster-II, but the lowest value was observed in cluster-V. The highest content of Iron was exhibited in cluster-V but the lowest result was observed in cluster-II. The highest cluster means for Zinc and total carotinoids were recorded in cluster-I but for the lowest observed in cluster-V. Crude protein content was exhibited the highest mean performance in cluster-III and cluster-IV respectively. But the lowest results were observed in cluster-V and Cluster –I, respectively.

Table 16: Mean value of 27 characters of the five clusters for the 12 potato cultivars tested at Debre Birhan in 2017

| Character | C-I | C-II | C-III | C-IV | C-V |
|---|---|---|---|---|---|
| DF | 68.67 | 70.35 | 79.15 | 70.15 | 74.9 |
| DM | 117.67 | 112.35 | 120.7 | 115 | 121.4 |
| PH | 54.9 | 52.7 | 40.25 | 46.5 | 51.5 |
| TNH | 10.57 | 12.5 | 15.4 | 6.2 | 9.3 |
| ATW | 68.33 | 51.15 | 30.9 | 68 | 64.6 |
| NMT | 385.33 | 398.5 | 228.5 | 198 | 320 |
| NUMT | 83.67 | 152 | 443.5 | 70 | 85.7 |
| NTT | 469.0 | 550 | 672 | 268.5 | 405.7 |
| MY | 30.67 | 26.07 | 14.74 | 17.3 | 24.8 |
| UMY | 1.14 | 1.94 | 5.5 | 0.97 | 1.2 |
| TY | 31.81 | 28 | 20.22 | 18.2 | 26 |
| LTY | 23.94 | 18.56 | 10.13 | 14.5 | 17.83 |
| LTP | 74.53 | 66.3 | 49.5 | 79.9 | 67.3 |
| MTYs | 5.44 | 6.26 | 3.4 | 1.9 | 5.9 |
| MST | 17.77 | 22.15 | 17.2 | 10.5 | 23.6 |
| STY | 2.42 | 3.18 | 6.7 | 1.8 | 2.3 |
| SST | 7.7 | 11 | 33.2 | 9.65 | 9.1 |
| TDM | 22.98 | 22.95 | 19.8 | 21 | 21.95 |
| SG | 1.088 | 1.090 | 1.078 | 1.077 | 1.088 |
| NE | 7.2 | 7.8 | 7.4 | 7.5 | 7.7 |
| Dg | 41.9 | 43.15 | 29.85 | 43.8 | 39.2 |
| SC | 16.47 | 16.45 | 13.6 | 14.7 | 15.6 |
| P | 1.11 | 1.11 | 1.08 | 0.98 | 0.9 |
| Fe | 35.27 | 24.35 | 40.2 | 33.2 | 43.9 |
| Zn | 36.07 | 43 | 39.95 | 35.5 | 22.1 |
| TC | 23.73 | 23.85 | 24.5 | 23.15 | 22 |
| CP | 9.04 | 9.36 | 11.05 | 11.35 | 9.1 |

PH= plant height, TNH=tuber number per hill, ATW=average tuber weight, MY=marketable yield $ha^{-1}$, UMY=Unmarketable yield $ha^{-1}$, TY=total tuber yield $ha^{-1}$, LTY= Large tuber yield $ha^{-1}$, LST= Large tuber size percentage, MST= medium tuber yield $ha^{-1}$, MST= medium tuber size percentage, MST= medium tuber yield $ha^{-1}$, SST= small tuber size percentage, TDM=tuber dry matter, SG=Specific gravity, Dg=Geometric diameter, P=Phosphorous %age, Fe=Iron mg/kg, Zn=zinc mg/Kg, TC=Total Carotinoids μg/g , CP= Crude Proteins %age.

From the result shown in Table 16, high yielder was in cluster I on contrary cluster IV had low yielder cultivars. Therefore comparison of means of various characters in different clusters revealed that clusters I showed higher performance for the most traits of interest. Regarding to quality cluster II and cluster III showed desirable aspects. The characters contributing maximum to the divergence are given greater emphasis for deciding on the cluster for the purpose of further selection and the choice of parents for hybridization.

Based on the traits studied for improvement of potato in appropriate breeding method based on the characters studied, variety Bubu could be used for yield characters, tuber dry matter content (%), tuber specific gravity, geometric diameter, starch content from cluster-I. Cluster I included potato varieties that are early flowering and early maturing cultivars. On the other hand, the highest cluster mean for total carotinoids, crude proteins, iron and zinc were recorded in cluster-III (Keydinich & Akime).But this cluster is characterized withlower tuber yield, average tuber weight and average specific gravity of tubers.According to the cluster mean analysis for characters, developing varieties for good quality and higher tuber yield through selection and further evaluation of cultivars from Cluster I and III is possible to obtain cultivars with highest total tuber yield, specific gravity oftuber, dry mater content, total starch content, total carotinoids, iron and zincwithother desirable traits.

Many investigators studied genetic variation of potato genotypes and found ample variation among genotypes in desirable traits including tuber yield and quality traits, and suggested that these traits can be improved through selection (Chala, 2018; Datta *et al.,* 2014;Ebrahim, 2018; Habtamu *et al*., 2016; Haydar *et al*., 2007; Mondal *et al.,* 2007; Lemma, 2018; Rangare and Rangare, 2017; Wassu, 2017).

### 4.4.5.Intra-and inter-cluster distances

It is important to consider the practical significance of grouping the cultivars into different clusters and estimating the genetic distance among them, which represents an index of genetic diversity among clusters. It may be useful to produce crosses between genotypes belonging to the clusters separated by large estimated distances (Bhatt, 1970). The average intra-and inter-cluster $D^2$ values and their square root (D value) are depicted in table 17. The intra-cluster distances ranged from 23.44 in cluster IV to 69.32 in cluster III. Clusters II and V respectively, had more or less similar intra-cluster distances (Table 17). The maximum inter cluster distance (553.83) was recorded between cluster III and IV while the minimum inter-cluster distance (93.11) was recorded between clusters I and V. Inter-cluster distance is the main criterion for selection of genotypes using D2 analysis. Genotypes belonging to the clusters with maximum inter-cluster distances are genetically more divergent and hybridization between genotypes of divergent clusters is likely to produce wide variability with desirable segregants (Sarma and Roy, 1994).The characters contributing maximum divergence needsgreater emphasis for deciding on the clusters for thepurpose of selection of parents in the respective clusterfor hybridization. The number of times, each of the yieldcomponent character appeared first in rank and itsrespective per cent of contribution towards geneticdivergence was presented (Table 17).

Mondal *et al.* (2007); Datta *et al.* (2015); Rangare and Rangare (2017)also reported that potato genotypes clusters constructed and that had higher mean values fordesirable traits including tuber yield and quality traits.Panigrahi *et al*. (2014) estimatedgenetic distances of all possible pairs of 17 potato genotypes in which the genetic distanceranged from 3.457 to 13.540.

Table 17: Average intra cluster (bold) and inter cluster (off diagonal) $D^2$ values among fiveclusters in 12 potato cultivars tested at Debre Birhan in 2017

| Cluster | I | II | III | IV | V |
|---|---|---|---|---|---|
| Cluster1 | **38.7** | 109.88 | 446.3 | 275.97 | 93.11 |
| Cluster2 | | **36.68** | 361.98 | 356.67 | 176.58 |
| Cluster3 | | | **69.32** | 553.83 | 458.31 |
| Cluster4 | | | | **23.44** | 186.23 |
| Cluster5 | | | | | **35.46** |

# 5. SUMMARY AND CONCLUSION

Potato is one of the most important and widely grown wholesome food crops in Ethiopia as well as many countries of the world and contributes immensely to human nutrition and food security to the growing global population. In Ethiopia in developing and releasingvarieties much emphasis was given for adaptability, productivity per unit area and late blight resistance. But selection of potato varieties should not be limited to high yield, but emphasis should also be given to internal and external quality of tubers. Therefore, this study was conducted at Debre Birhan agricultural research center during the 2017 main cropping season with the objectives of assessing the genetic variation of potato cultivars for tuber yield, yield related characters and tuber quality and also to determine association among characters, and the direct and indirect effects of yield related and tuber quality characters on total tuber yield.

The highest small sized tubers percentage was obtained from farmers' cultivars. The highest total tuber yield (36.86 t $ha^{-1}$) was obtained from the improved variety Bubu followed by Gera (31.21 t $ha^{-1}$). Bubu also produced the highest average tuber weight. The farmer's cultivar Keydinich had tubers with the highest concentrations of total carotinoids. The improved varieties, Bubu andAlemaya-624 had highest concentrations of starch content but Menagesha had high concentration of crude protein. Dinkey produced tubers with the lowest mean values for chemically analyzed quality characters of tubers. The observed differences among genotypes for the various traits suggested the existence of genetic variation among the studied varieties. This variability could be harnessed to gain improvement in quality, yield and its attributing characters following appropriate breeding methods in the study area.

The phenotypic coefficients of variation (PCV) values were higher than genotypic coefficients of variation (GCV) values for all the traits studied indicating that apparent variations in the genotypes were not only due to genotypic effect but also due to environmental influences, since phenotypic variances contributed to the expression of the traits. GCV and PCV values of the 27 characters ranged from 0.79 to 88.9% and 0.84 to 92.43%, respectively. Heritability in broad sense and genetic advance as percent of mean ranged from 65.35% to 97.53% and 1.63% to 183.52%, respectively. High heritability values were coupled with high genetic advance for all characters except for total carotinoids, starch content and tuber dry matter content for which the genetic advance values were moderate. GAM was low for days to maturity and specific gravity of tubers. The results suggested that the majority of the studied characters exhibited high GCV, PCV, heritability and genetic advance as percent of mean and can be improved through selection of cultivars with high mean performance for the respective characters.

The genotypic correlation coefficients were higher than corresponding phenotypic correlation coefficients. Total tuber yieldshowed highly significant positive genotypic and phenotypic association with plant height, average tuber weight, marketable tuber yield,starch content, large size tuber percentageand geometric mean diameter, and negative correlated with unmarketable tuber yield, small size tuber percentage, ironand crude protein.But there is no correlation between total tuber yield ha$^{-1}$ and phosphorous, medium size tuber percentageand total carotinoids.Then tuber yield can be improved independently from phosphorous content and the amount of total carotenoids in the tuber. Therefore, plant height, average tuber weight, marketable tuber yield, starch content, large size tuber percentage and geometric mean diameter will havepractical importance in selection of potato genotypes for high total tuber yield per hectare andtuber quality characters.

Cluster analysis based on the average values of the studied characters resulted in the grouping of the potato cultivars in to five major clusters. Released and farmer's cultivars were grouped under the same cluster in three of the five clusters. Based on the traits studied for improvement of potato in appropriate breeding method, Cluster I included potato cultivars that are early flowering, early maturing cultivars, high in average tuber weight and starch content. On the other hand, the highest cluster mean for total carotinoids, crude protein, iron and zincwere recorded in cluster-III (farmer's cultivar Keydinich & Akime) but low in total tuber yield $ha^{-1}$.Analysis of thecluster mean for characters revealed the possibility of obtaining or developing varieties withhighest total tuber yield, specific gravity oftuber, dry mater content, total starch content, total carotinoids, iron and zincwithother desirable traits.The research results indicated the presence of wide variations among potato cultivars for tuber yield, yield components and tuber quality. This variability can potentially be exploited in futureimprovement in the potato breeding program.

However, it is difficult to make conclusions from an experiment conducted at only one location for one season. Therefore, it is recommended thatthese cultivars along with other released cultivars be evaluated across a number of locations for a number of seasons for their performance in tuber yield and tuber quality.

# 6. REFFERENCES


Abraham Lamboro, Yohannes Petros and Mebeaselassie Andargie, 2014.Correlation and path coefficient analysis between yield and yield components in potato (*Solanum tuberosum* L.)Plant Science Today, 1(4), 196-200. doi: 10.14719/pst.2014.1.4.79.

Acquaa, 2007.Principles of plant genetics and breeding.Blackwell pubishing, Maden, MA, USA.

Adane Hirpa, Miranda P. M., Willemien M., Lommen J. M., Admasu T., P.C., Struik, Alfons G. J. M.and Lansink O., 2015. Least-Cost Seed Potato Production in Ethiopia American jornal of potato research.Springerlink 58:277–300.

Adane HM, Meuwissen PM, Agajie TM, Willemien J, Lommen A, Oude L, Admasu T and PC Struik, 2010. Analysis of seed potato systems in Ethiopia. American Journal of Potato Research; 87:537–552: DOI:10.1007/s12230-010-9164-1.

Addisu Fekadu, Yohannes P. and Habtamu Z. 2013.Genetic variability and association between agronomic characters in some potato (*Solanum tuberosum* L.) genotypes in SNNPRS, Ethiopia.IJBC: 5(8): 523-528.

Akhavan S, Moosavi S.F., Mostafazadeh P. and Gadami A., 2007.Study of drip and furrow irrigation with regard to yield and WUE in potato cultivation. J Sci Tech Agric Nat Resour, 11 (41): 15-26.

Allard, R.W. 1960. Relationship between genetic diversity and consistency of performance in different environment: Crop Sci., **1**: 127-123.

Amjad A., Randhawa M.A., Butt M.S. and Asghar M., 2016. Assessing the Processing Quality of Different Potato Cultivars during Storage at Various Temperatures.J.Chem.Soc.Pak.: 38(05), 1005-1013.

Andre, C.M., M. Ghislain, P. Bertin, M. Qufir, M.D.R. Herrera, L. Hoffmann, J.F.O.Hausman, Y. Larondelle and D. Evers. 2007. Andean potato cultivars (*Solanum tuberosum* L.) as a source of antioxidant and mineral micronutrients. J. Agric. Food Chem. 55: 366–378.

AOAC (Association of Official Analytical Chemists). 1980. Official methods of analysis. Gaithersburg, Md.

Arsenal Frankford**,** 1974.Spectrophotometric Determination of Trace Amounts of Silicon, Iron, and Aluminum in Nitrocellulose-Base Propellants, Philadelphia, Pennsylvania 19137.

Arslanoglu, F., Aytac, S. and Oner, K. 2011. Morphological characterization of the local potato (*Solanum tuberosum* L.) genotypes collected from the Eastern Black Sea region of Turkey. *African Journal of Biotechnology*, 10(6): 922-932.

Asmamaw Y., Tsegaw T. and Seyoum T., 2010. Specific gravity, dry matter concentration, pH, and crisp-making potential of Ethiopian potato (*Solanum tuberosum* L.) cultivars as influenced by growing environment and length of storage under ambient conditions.*Potato Research*, 53: 95–109.

Asmamaw Yeshanew. 2007. Post harvest quality of potato (*Solanum tuberosum* L.) cultivars as influenced by growing environment and storage period. M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia.

Bala S.R. and Rangare N.R., 2017.Classificatory analysis of potato (*Solanum tuberosum*L.)Genotypes for yield and yield attributing traits. The Pharma Innovation J.; 6(8): 94-102.

Baye Brehanu. 2002. Variability and Association of tuber yield and related trait in potato (*Solanum tuberosum* L.). MSc. Thesis pp: 41-49. Haramaya University, Haramaya.

Beukema HP. and Zaag V. D., 1990.Introduction to potato production. Centre for Agricultural Publishing and Documentation, Wageningen.

Burhan, A. 2007. Relationship among yield and some yield characters in potato. *Journal of Biological science*, 7:973-976.

Burton, G.W. and De vane E.H., 1953. Estimating heritability in tall fenscue (*Festeca arundina ceae*) from replicated clonal material. Agron. J., 45: 478-481.

Camire M, Kubow S.and Donnelly D.J., 2009.Potatoes and human health.Critical Reviews FoodScience Nutrition, 49:823-840.

Cavatassi, R., L. Lipper, and U. Narloch. 2011. Modern variety adoption and risk management in drought prone areas: insights from the sorghum farmers of Eastern Ethiopia. Agricultural Economics 42: 279–292.

Chala Obsa, 2018. Genetic variability, correlation and path coefficient analysis in potato (*Solanum Tuberosum*L.) genotypes for yield, yield related traits and mineral contents at Haramaya, Ethiopia.Unpublished Msc. Thesis Submitted to School of Plant Sciences, Haramaya University, Ethiopia.

CSA (Central Statistical Authority), 2016a.Agricultural Sample Survey 2015 /2016. Reports on forecast of area and production of major crops: Rural Private Peasant holding s.' Belg ' season. Statistical Bulletin 578. Addis Ababa, Ethiopia.

CSA (Central Statistical Authority), 2016b.Agricultural Sample Survey 2015 /2016. Reports on forecast of area and production of major crops: Rural Private Peasant holding s.' Meher ' season. Statistical Bulletin 584. Addis Ababa, Ethiopia.

Datta S., Das R., Singh D., Thapa U. and Mandal A., 2014. Study of correlation among various characters of different potato (*Solanum tuberosum*L.) gerplasm .J.Crop Weed,10:186-88.

Deshmuk, SN., Basu MS. and Reddy PS., 1986. Genetic variability character association and path coefficient analysis of quantitative traits in Virgina bunch varieties in plant breeding. Indian J. Agri. Sci. 56:816 - 821.

Deway, D.R. and Lu, K.H. 1959. A correlation and path coefficient analysis of components of crested wheat grass and seed production.Agron. J. 5: 515-518.

Ebrahim Seid, 2018. Genetic variability in potato (*solanum tuberosum L.*) genotypes for tuber quality, yield and yield related traits at Holetta, central highlands of Ethiopia.MSc Thesis, Haromaya University, Dire Dawa, Ethiopia.

Ekin, Z. 2011. Some analytical quality characteristics for evaluating the utilization and consumption of potato (S*olanum tuberosum* L.) tubers.Afr. J. Biotec. 10(32): 6001–6010.

Elfnesh F., Tekalign T. and Solomon W., 2011.Processing quality of improved potato (*Solanum tuberosum* L.) cultivars as influenced by growing environment and blanching. African Journal of Food Science, 5(6):324-332.

Engida Tsegaye, Nigussie Dechasa and Devakara, E.V. 2007.Genetic Variability for yield and other agronomic traits in sweet potato.*Journal of agronomy.*6(1): 94-99.

Esendal, E., 1990. Potato. University of Ondokuz Mayis, Faculty of Agriculture, No: 49. ISBN: 975-7636-06-1, Samsun, Turkey, p 221.

Ezekiel, R., Singh, N., Sharma, S. and Kaur, A. 2013.Beneficial phytochemicals in potato a review.Food Research International, 50(2): 487-496.

Falconer D. and Mackay F., 1996.Introduction to Quantitative Genetics. Longman, New York. P. 464.

FAO. 2008. Potato World: Africa—International Year of the Potato 2008. http://www.potato2008.org/en/world/africa.html. Date of access: 1/1/2019

FAOSTAT, 2015. FAO Statistical Pocketbook: World Food and Agriculture. Rome, Italy.

FAOSTAT, 2018. Agricultural Data.Provisional 2016 Production and Production Indices Data.Crop primary.Food and Agriculture Organization of the United Nations, Rome, Italy.

Fayera W.N., 2017. Yield and yield components of potato (*Solanum tuberosum* L.) as influenced by planting density and rate of nitrogen application at Holeta, West Oromia Region of Ethiopia, Afr. J. Agric. Res.: 12 (26), 2242-2254

Fonseca, S. and Patterson, F.L. 1968. Yield component heritabilities and interrelationships in winter wheat (*Triticumaestivum* L.). *Crop Science*, 8(5): 614-617.

Gebremedhin, W.G., Endale, G. and Berga, L. 2008. Root and Tuber Crops.EIAR. Addis Ababa, Ethiopia.

Gebremedhin, W. 2013.Potato variety development strategies and methodologies in Ethiopia. In: Gebremedhin, W., Schulz, S. and Baye, B. (Eds.). Seed potato tuber production and disseminations, experiences, challenges and prospects.pp.45 - 59 Ethiopian Institute of Agricultural Research and Amhara Region Agriculture Research Institute, 12 - 14 Mach 2012, Bahir Dar, Ethiopia.

Getachew Asefa and Tesfaye Abebe, 2016.Genetic Variability Studies in Potato (Solanum Tuberosum L.) Genotypes in Bale Highlands, S. Esern Ethiopia, IJAdAgSc: (1)1: 22-28.

Getachew Asefa, Wassu Mohammed and Tesfaye Abebe, 2016.Evaluation of Potato (Solanum tuberosum L.)Genotypes for Resistance to Late Blight at Sinana Southeastern Ethiopia.Int. J. Agril. Res. Innov. & Tech. 6 (1): 21-25.

Gildemacher P., Demo P., Barker I., Kaguongo W., Gebremedhin W., Wagoire W., Wakahiu M., Leeuwis C. and Struik PC., 2009. A description of seed potato systems in Kenya, Uganda and Ethiopia.Am J Potato Res 86: 373–382.

Gomez, A.K. and A.A. Gomez, 1984.Statistical Procedures for Agricultural Research. (2nd ed.). An International Research Institute Book.John Willey and Sons Inc. New York.

Gumul D., Ziobro R., Noga M. and Sabat R., 2011.Characterisation of five Potato Cultivars according to their Nutritional and pro-health components, Acta Sci. Pol., Technol. Aliment. 10(1), 73-81.

Guta Eshetu., 2017. Review on Compost and Mineral NP-fertilizer Application Rate Effects on the Yield and Yield Components of Potato (*Solanum tuberosum* L.). Science, Technology & Public Policy. Vol. 1, No. 1, pp. 7-11. doi: 10.11648/j.stpp.20170101.12.

Haase, T., Schüler, C., and Heb, J. 2007. The effect of different N and K sources on tuber nutrient uptake, total and graded yield of potatoes (*Solanumtuberosum*L.) for processing.European Journal of Agronomy, 26: pp. 187-197.

Habtamu G., Wassu M. and Beneberu S., 2016a.Evaluation of physicochemical attributes of potato varieties in eastern Ethiopia, Greener Journal of Plant Breeding and Crop Science. 4 (2), pp. 027-036. DOI: http://doi.org/10.15580/GJPBCS.2016.2.102315147.

Habtamu G., Wassu M. and Beneberu S., 2016b.Evaluation of Potato (Solanum tuberosum L.)Varieties for Yield and Yield Components in Eastern Ethiopia, Journal of Biology, Agriculture and Healthcare. 6 (5):146-154.

Hair, J.R., Anderson, R.E., Tatham, R.L. and Black, W.C. 1995.Multivariate Data Analysis with Readings.4th Ed., Prentice-Hall, Englewood Cliffs, NJ.

Hamdi A, El-Ghareib AA, Shafey SA and Ibrahim MAM., 2003. Genetic variability, heritability and expected genetic advance for earliness and seed yield from selection in lentil. Egy. J.Agric. Res 81(1): 125-137.

Hawkes J., 1990. The potato evolution, biodiversity and genetic resources. Oxford: B press.

Hawkes JG., 1994. Origins of cultivated potatoes and species relationships In: Bradshaw JE, Mackay GR (eds) Potato genetics. CAB International, Wallingford.

Haydar, A., Ahmed, M.B., Hannan, M.M., Razvy, M.A., Mandal, M.A., Salahin, M., Karim, R. and Hossain, M. 2007.Analysis of genetic diversity in some potato varieties grown in Bangladesh.*Middle-East Journal of Scientific Research*, 2(3-4): 143-145.

Haydar A., Islam M., Ara T., Khokan E. and Khalequzzaman K., 2009.Studies on Genetic Variability, Correlation and Path Analysis in Potato.In. J. Susta. Agril.Tech.5(5) 40-44.

Haymanot Awgechew, Heluf Gebrekidan and Adamu Molla, 2015.Nutrient status of potato (*Solanum tuberosum L.*) Tubers and Lettuce (*Lactuca sativa L.)* produced along the bank of river Beressa. J.A.F. 7(8), 180. 7(8), 179-185. DOI: 10.5897/JHF20153851.

Heinfnings, J.W. 1987. Late blight of potato (*Phytophthora infestans*), Technical information Bulletin 4. Lima. Peru.25pp.

Hijmans,R.J. and D.M. Spooner, 2001. Geographic distribution of wild potato species. Am. J. Bot. 88: 2101–2112.

Horton, D., and Sawyer, RL. 1985. The potato as a world food crop, with special reference to developing areas. In: Li PH, ed. potato physiology. London, Academic Press 1-34.

Huaman Z. and Spooner DM., 2002. Re-classification of landrace populations of cultivated potatoes (Solanum sect.Petota).Am J Bot. 89:947-965.

Huaman Z., 1991. Descriptor for sweet potato.IBPGR, Rome, Italy.

Jamaati-e-Somarin, S., A. Tobeh, M. Hassanzadeh, M. Saeidi, A. Gholizadeh and R. Zabihi-eMahmoodabad. 2008. Effects of different plant density and nitrogen application rate on nitrogen use efficiency of potato tuber. Pakistan. J. Biol. Sci., 11(15): 1949-1952.

Johnson, H. W., Robinson, H. F. and Comstock, R. E. 1955.Estimates of genetic and environmental variability in Soybean.Agronomy Journal, 47, 314-318.

Kabira J. and Berga L., 2003. Potato processing quality evaluation procedure for research and food industry applications in east and central Africa.Kenya Agric Res Insti. Nairobi.

Khayatnezhad, M.R, Shahriari, B.R, and Gholamin, R.G., 2011.Correlation and path analysis between yield and yield components in potato (*Solanum tubersum* L.).*Journal of sciences research*. 7(1): 17-21.

Kirkman, M.A. 2007. Global markets for processed potato products. pp. 27-44. *In* D. Vreugdenhil, (Ed.).P B and Biotechnology Advances and Perspectives.Elsevier, Oxford.

Kleinkopf G.E., Westermann D.T., Wille M.J. and Kleinscmidt G.D., 1987. Specific Gravity of Russet Burbank Potatoes.American Journal of Potato, 64: 579-587.

Krinsky, N.I., Mayne, S.T. and Sies, H., 2004. Carotenoids in health and disease. CRC Press, New York.

Kromann, P., Miethbauer, T., Ortiz, O., Forbes, G.A. 2014. Review of potato biotic constraints and experiences with integrated pest management interventions. *Integrated PestManagement Experiences with Implementation*, 4: 245-268.

Kumar K.P., Pradhan J., Panigrahi P. and Sarkar K., 2017.Genetic Variability, Character Association and Path Coefficient Analysis of Yield Attributes for Medium and Late Maturing Potato Cultivars.Int.J.Curr.Microbiol.App.Sci. 6(7): 2558-2566.

Kyamanywa, S., I., Kashaija, E., Getu, R., Amata, N. Senkesha, and Kullaya, A. 2011.Enhancing Food Security through Improved Seed Systems of Appropriate Varieties of Cassava, Potato and Sweet potato Resilient to Climate Change in Eastern Africa. Nairobi, Kenya, ILRI.

Larik A., Malik S., Kakar A. and Naz MA., 2000. Assesment of heritability and genetic advance for yield and yield components in Gossypium hirsutum L. Scientific Khyber 13: 39-44.

Lemma Tessema, 2018. Genetic Improvement of Potato *(Solanum tuberosum* L.*)* Varieties for Tuber Yield and Associated Traits in central Ethiopia.MSc Thesis, Haromaya University, Dire Dawa, Ethiopia.

Liu Q., Weber E., Currie V, and Yada R., 2003.Physicochemical properties of starches during potato growth.Carbohydr.Polym., 51: 213-221.

Lung'aho, C., Lemaga B., Nyongesa M., Gildermacher P., Kinyale P., Demo P. and Kabira J., 2007. Commercial seed potato production in eastern and central Africa.Kenya Agricultural Institute. 140p.

Machida-Hirano Ryoko, 2015. Diversity of potato genetic resources: Review. Breeding Science: 65(1): 26–40 doi : doi:10.1270/jsbbs.2015.65.26.

Mekonen S., Alemu T., Kassa B. and Forbes G., 2009. Evaluation of contact fungicide sprays regimes for control of late blight (*Phytophthora infestans*) in southern Ethiopia using potato cultivars with different levels of host resistance. Tro.Plant Patho. 361:021-027.

Miller, D.A., Williams, J.C., Robinson, H.F. and Compstock, K.B. 1958. Estimation of genotypic variance and covariance in upland cotton.Agron. J. 50: 126-131.

Mishra S., 2016. Genetic Variability and Character Association for Yield and its Attributing Traits in Potato (*Solanum Tuberosum*L.).Msc. Thesis, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya Raipur (Chhattisgarh), India. 115pp.

Mishra, A.C. Singh, N.P. Shashi Kamal. and Virender Kumar. 2006. Studies on genetic variability, heritability and genetic advance in potato (Solanum tuberosumL.), International Journal of Plant Sciences Muzaffarnagar. 1(1): 39- 41.

Mitiku M., Shiferaw W. and Tadesse A. 2014. Adaptability Study of Improved Irish Potato (*Solanum tuberosum* L.) Varieties at South Arisi Woreda, Ethiopia. ASRJETS7(1):26-30.

MoANNR (Ministry of Agriculture and Natural Resources). 2016. Crop Variety register Issue No. 19. Addis Ababa, Ethiopia.

Mode, C.J. and Rhobinson, H.F. 1959.Pleotropism and genetic divergence and covariance.Biometrics 15:518-537.

Mohsenin NN. 1970. Physical properties of plant and animal material. New York. Gordon and Breach.

Mondal, M.A.A., Hossain, M.M., Rasul, M.G. and Uddin, M.S. 2007. Genetic diversity in potato (*Solanum tuberosum* L.). Bangladesh Journal of Botany, 36(2): 121-125.

Mondal. M. A. A. 2003. Improvement of Potato *(Solanum tuberosum* L.) through hybridization and invitroculturetechnique.Ph.D.Thesis, Rajshahi University, Rajshahi, Bangladesh.

Morris W., Ducreux L., Griffiths D., Stewart D., Davies H. V. and Taylor M., 2004**.**Carotenogenesis during tuber development and storage in potato.J. E. Bot.399, 975-982.

Muhinyuza JB, Shimelis H., Melis R, Sibiya J., Daphrose G. and Nzaramba MN., 2014. Yield and yield components response of potato genotypes in selected agro-ecologies of Rwanda, Res. on Crops 15 (1): 180-191. doi:10.5958/j.2348-7542.15.1.025.

Nasiruddin M., FM Ali Haydar and Rafiul Islam, 2017.Genetic diversity in potato (*Solanum tuberosum*L.) genotypes grown in Bangladesh Int. Res. J. Biological Sci. 6(11), 1-8.

Nechif O., Filimon R. and Szilagyi L., 2011. "Genetic variability, heritability and expected genetic advance as indices for yield and yield components selection in common bean (Phaseolus vulgaris L.)," Scientific Papers, UASVM Bucharest, Series A 1222-5339.

Ntawurunga P., Rubaihayo P.R., Whyte J.B., Dixon A.G. and Osiru D.S., 2001. Inter-relationships among traits and path analysis for yield components of cassava: A search for Storage Root Yield Iindicators. In: African Crop Science Journal, 9(4)

Nyquist W.E. 1991. Estimation of heritability and prediction of selection responses in plant populations. Crit. Rev. Plant Sci. 10: 235-322.

Otroshy, M., 2006.Utilization of tissue culture techniques in a seed potato tuber production scheme.PhD Thesis, Wageningen University.P. 264.

Ovchinnikova A., Krylova E., Gavrilenko T., Smekalova T., Zhuk M., et al., 2011. Taxonomy of cultivated potatoes (*Solanum*section *Petota: Solanaceae*). Bot. J. Linn. Soc. 165:107–155.

Panigrahi, K.K., Pradhan, J., Panigrahi, P. and Sarkar, K.K. 2017. Genetic Variability, Character Association and Path Coefficient Analysis of Yield Attributes for Medium and Late Maturing Potato Cultivars. *International Journal of Current Microbiology and Applied Sciences, 6*(7): 2558-2566

Panigrahi, K.K., Sarkar, K.K., Baisakh, B. and Mohanty, A. 2014.Assessment of genetic divergence in potato (*Solanum tuberosum* L.) genotypes for yield and yield attributing traits.*International Journal of Agriculture, Environ. and Biotec.*, 7(2): 247-254.

Pankhrust, R., 1964. Notes for a history of Ethiopian agriculture, Ethiopian Obser 7: 210-240.

Rahman MA, Kabir ML, Hasanuzzaman M, Rumi RH, and Afrose MT., 2016. Study of variability in bread wheat (Triticum aestivum L.). Int. J. Agric. Res. 8:66-76.

Rangare, S.B. and Rangare, N.R. 2017.Classificatory analysis of potato (*Solanum tuberosum* L.) genotypes for yield and yield attributing traits.*The Pharma Innovati*, *6*(8): 94- 102.

Robertson, A. 1959. Experimental design in the evaluation of genetic parameters. *Biometrics*, 15(2): 219-226

Robinson, H.F., Comstock R.E. and Harvey V.H., 1949. Estimates of heritability and degree of dominance in corn.J.Agron.41: 353-359.

Roy T.S., Chakraborty R., Md. Parvez N, Mostofa M., Ferdous J. and Salma A., 2017. Yield, Dry Matter and Specific Gravity of Exportable Potato: Response to Salt. Universal Journal of Agricultural Research 5(2): 98-103,

SAS., 2002. Statistical Analysis Software 9.1. SAS Institute Inc. Cary, NC, USA.

Sattar M., Sultana, M., Hossain, M. and Rashid A., 2007.Genetic variability, correlation and path analysis in potato (*Solanum tuberosum*L.).Bangladesh J. Pl. Breed.Genet.20(1): 33-38.

Semagn A., Halseth D., De Jong W., Perry K. *et al*., 2015. Potato Variety Diversity, Determinants and Implications for Potato Breeding Strategy in Ethiopia. Am. J. Potato Res. 92:551–566. DOI 10.1007/s12230-015-9467-3.

Shayanowaka A., Mangini R., Mtaita T. and Upenyu M., 2014.Effect of stem density on growth, yield and quality of potato variety amethyst.Africa JAgr. Research, 9(17): 1391-1397.

Singh B.D. 1990. Plant breeding, *Kalyani Publishers*, New Delihi, India.pp. 702.

Singh P. and S.S. Narayanan, 1993.Biometrical Techniques in Plant Breeding. Kalyani Publishers, New Delhi, India, pp: 7484.

Singh, B.D., 2001. Plant Breeding: Principles & Methods. Kalyani Publishers, New Delhi. 896p.

Spooner D. and Salas, A. 2006.Structure, biosystematics, and genetic resources.Pages 139 in J. Gopal, S. M. P. Khurana, eds. (editions) Handbook of potato production, improvement and postharvest management.Food Products Press, Binghamton, NY (New York).

Spooner D.M. and Bamberg J.B., 1994. Potato genetic resources: sources of resistance and systematics. Am. Potato J. 71: 325–337.

Spooner D.M., 2009. DNA barcoding will frequently fail in complicated groups: an example in wild potatoes. Am. J. Bot. 96: 1177–1189.

Spooner D.M., Ghislain, M., Simon, R., Jansky, S.H. and Gavrilenko, T. 2014.Systematics, Diversity, Genetics and Evolution of wild and cultivated potatoes. Bot. Rev., 80: 283-383.

Spooner DM. and Knapp, S. 2013. *Solanum tuberosum*. [12 December 2018].

Sriom, D.P. Mishra, Rajbhar P., Singh D., Kumar R.S. and Kumar S.M., 2017.Effect of different levels of nitrogen on growth and yield in potato (*Solanum tuberosum* L.) CV. Kufri Khyati. Int.J.Curr.Microbiol.App.Sci.6(6):1456-1460.

Stark J., Novy R., Whitworth J., Love S., Corsini, D., Pavek, J., … Olsen, N. 2009. Highland Russet: A full season, processing variety with high yields of uniform U.S. No. 1 Tubers. American Journal of Potato Research, 86(1), 171–182.

Storey M., 2007.The Harvested Crop. pp. 441-470. In: Vreugdenhil, D., Bradshaw, J., Gebhardt, C., Govers, F., Taylor, M.A., MacKerron, D.K. and Ross, H.A. (eds.), Potato Biology and Biotechnology: Advances and Perspectives. Elsevier, London.

Storey R.M.J. and Davies H.V. 1992.Tuber quality. In: Harris PM (Ed.). The Potato Crop: The Scientific Basis for Improvement, Chapman Hall, London, pp. 507-552.

Struick P., Haverkort A., Vreugdenhil D., Bus C. and Dankert R., 1990. Manipulation of tuber-size distribution of a potato crop. Potato Research, Wageningen, v.33, p.417-432.

Tai G.C. and Young D.A., 1984.Early generation selection for important agronomic characteristics in a potato breeding population. Amer. Potato J. 61, 419-434.

Tazeen M., Nadia K. and Farzana NN. 2009. Heritability, phenotypic correlation and path coefficient studies for some agronomic characters in synthetic elite lines of wheat. J. Food. Agric. Environ. 7(3&4): 278 -282.

Tekola Teshome, 2014. Genetic variability in agronomic characters and tuber quality of potato genotypes (*solanum tuberosum* l.) in East Hararghe, Ethiopia.Unpublished Msc. Thesis Submitted To School Of Plant Sciences, Haramaya University, Ethiopia.

Tesfaye Abebe, Shermarl W. and Thunya T., 2013.Evaluation of specific gravity of potato varieties in Ethiopia as a criterion for determining processing quality. Kasetsart Journal *(Natural Science)*, 47:30- 41.

Tesfaye Abebe, Shermarl, W., Thunya, T. and Oranuch, L. 2012. Dry matter content, starch content and starch yield variability and stability of potato varieties in Amhara Region of Ethiopia. *Kasetsart Journal (Natural Science)*, 46(5): 671-671.

Tripura A., Das A., Das B., Priya B. and Sarka K.K.., 2016. Genetic studies of variability, character association and path analysis of yield and its component traits in potato (*Solanum tuberosum*L.). Journal of Crop and Weed, 12(1):56-63.

Van Gelder, N.M. and Parent, M., 1981, Effect of protein and taurine content of maternal diet on the physical development of neonates, Neurochem. Res. 200:443–455.

Wassu Mohammed, 2017. Genotype x environment interaction, stability and coheritability of tuber internal quality traits in potato (*Solanum Tuberosum* L.) cultivars in Ethiopia.*African Journal of* Food Agric. Nutr.and Dev., 17(4): 12930-12952.

Wassu Mohammed. 2016. Specific gravity, dry matter content, and starch content of potato (*Solanum tuberosum* L.) varieties cultivated in Eastern Ethiopia. East African Journal of Science, 10(2): 87-102.

Webster, R. and M. Oliver, 1990.Statistical Methods in Soil and Land Resource Survey (patial Information Systems).Oxford University Press. London. Pp. 316.

# 7. APPENDIXES

Appendix Table I. Long term monthly rainfall data 1985-2015, Debre Birhan Agricultural Research Meteorology Station

| year | JAN | FEB | MAR | APR | May | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 17.40 | 0.00 | 49.40 | 58.60 | 83.20 | 15.80 | 314.60 | 376.60 | 88.40 | 6.50 | 5.70 | 0.00 | 1016.20 |
| 1986 | 0.00 | 74.70 | 99.20 | 52.50 | 27.00 | 141.90 | 271.30 | 274.70 | 115.70 | 11.30 | 0.00 | 0.00 | 1068.30 |
| 1987 | 5.00 | 19.20 | 108.10 | 51.70 | 100.20 | 0.00 | 32.30 | 309.50 | 47.50 | 18.70 | 0.00 | 6.30 | 698.50 |
| 1988 | 10.60 | 34.60 | 16.90 | 83.10 | 16.20 | 16.00 | 286.20 | 290.00 | 153.10 | 12.10 | 0.00 | 0.00 | 918.80 |
| 1989 | 2.30 | 40.50 | 97.60 | 42.70 | 1.40 | 41.10 | 211.40 | 177.40 | 67.70 | 18.60 | 0.00 | 30.70 | 731.40 |
| 1990 | 0.00 | X | x | 59.50 | 0.90 | 1.60 | 320.90 | 217.20 | 168.70 | 0.60 | 0.00 | 0.00 | 769.40 |
| 1991 | 4.80 | 8.30 | 64.60 | 21.00 | 12.00 | 63.70 | 215.60 | 387.50 | 86.60 | 6.40 | 0.00 | 6.40 | 876.90 |
| 1992 | 30.30 | 26.70 | 24.40 | 80.20 | 19.30 | 13.30 | 307.60 | 267.60 | 92.90 | 41.90 | 0.50 | 1.80 | 906.50 |
| 1993 | 4.30 | 63.20 | 0.00 | 116.90 | 60.50 | 9.10 | 405.50 | 168.40 | 107.70 | 43.20 | 0.00 | 1.10 | 979.90 |
| 1994 | 0.00 | 0.00 | 95.60 | 0.00 | 23.20 | 92.70 | 281.70 | 222.90 | 101.70 | 0.00 | 36.50 | 0.00 | 854.30 |
| 1995 | 0.00 | 28.50 | 19.10 | 68.40 | 26.50 | 23.30 | 273.80 | 233.80 | 60.40 | 5.10 | 0.00 | 1.70 | 740.60 |
| 1996 | 20.70 | 2.80 | 75.40 | 9.70 | 129.20 | 138.00 | 336.40 | 252.50 | 24.30 | 0.00 | 3.00 | 0.00 | 992.00 |
| 1997 | 29.50 | 4.00 | 41.20 | 82.40 | 25.90 | 95.10 | 272.10 | 200.60 | 34.80 | 89.70 | 30.50 | 0.10 | 905.90 |
| 1998 | 26.70 | 13.20 | 14.90 | 49.30 | 43.00 | 13.50 | 337.30 | 289.00 | 70.60 | 5.20 | 0.00 | 0.00 | 862.70 |
| 1999 | 6.90 | 0.00 | 26.50 | 2.80 | 11.80 | 48.90 | 362.40 | 365.10 | 52.40 | 59.60 | 1.40 | 0.00 | 937.80 |
| 2000 | 0.00 | 0.00 | 25.90 | 47.30 | 37.10 | 46.60 | 352.40 | 317.50 | 105.20 | 28.50 | 18.80 | 6.80 | 986.10 |
| 2001 | 0.00 | 33.80 | 71.20 | 18.80 | 64.60 | 34.90 | 406.30 | 260.40 | 32.20 | 4.10 | 0.00 | 3.40 | 929.70 |
| 2002 | 18.10 | 28.00 | 60.60 | 46.10 | 18.40 | 29.10 | 214.40 | 295.80 | 109.10 | 3.10 | 0.00 | 8.40 | 831.10 |
| 2003 | x | X | x | x | x | X | X | x | x | x | x | x | x |
| 2004 | 24.40 | 34.10 | 29.70 | 29.70 | 143.00 | 5.60 | 105.30 | 334.70 | 380.20 | 14.00 | 25.80 | 0.00 | 1126.50 |
| 2005 | 34.30 | 38.80 | 28.60 | 28.60 | 78.00 | 76.40 | 167.50 | 310.70 | 0.00 | 0.00 | 0.00 | 0.00 | 762.90 |
| 2006 | 17.30 | 41.70 | 61.00 | 61.00 | 99.30 | 19.80 | 55.00 | 432.60 | 292.00 | 8.60 | 8.60 | 26.30 | 1123.20 |
| 2007 | 2.00 | 32.90 | 16.10 | 16.10 | 37.30 | 13.60 | 92.70 | 321.50 | 534.30 | 0.00 | 5.70 | 0.00 | 1072.20 |
| 2008 | 0.30 | 2.00 | 0.00 | 0.00 | 34.60 | 67.90 | 134.30 | 397.70 | 310.60 | 9.90 | 64.50 | 1.20 | 1023.00 |
| 2009 | 62.10 | 0.00 | 8.20 | 31.40 | 14.90 | 6.80 | 435.10 | 273.20 | 30.50 | 36.60 | 1.20 | 24.70 | 924.70 |
| 2010 | 0.00 | 25.20 | 55.70 | 119.30 | 52.00 | 35.40 | 242.30 | 329.20 | 53.80 | 0.30 | 8.50 | 3.90 | 925.60 |
| 2011 | 0.30 | 7.00 | 76.80 | 38.60 | 111.20 | 84.40 | 357.40 | 312.30 | 79.00 | 0.00 | 4.30 | 0.00 | 1071.30 |
| 2012 | 0.00 | 0.00 | 8.50 | 65.50 | 36.00 | 196.00 | 429.50 | 356.90 | 134.70 | 0.00 | 0.00 | 13.00 | 1240.10 |
| 2013 | 4.20 | 0.00 | 23.10 | 55.20 | 35.50 | 54.50 | 435.60 | 342.20 | 92.00 | 134.40 | 8.30 | 0.00 | 1185.00 |
| 2014 | 3.40 | 0.00 | 29.70 | 35.40 | 35.20 | 42.10 | 427.60 | 313.90 | 113.30 | 44.90 | 0.00 | 1.20 | 1046.70 |
| 2015 | 0.00 | 0.00 | 18.80 | 0.00 | 72.90 | 53.00 | 100.20 | 160.7 | 34.6 | 0 | 12.3 | 3 | 455.50 |
| Ave | 10.83 | 19.28 | 42.99 | 45.73 | 48.34 | 49.34 | 272.82 | 293.07 | 119.13 | 20.11 | 7.85 | 4.67 | 934.17 |

x: no data available

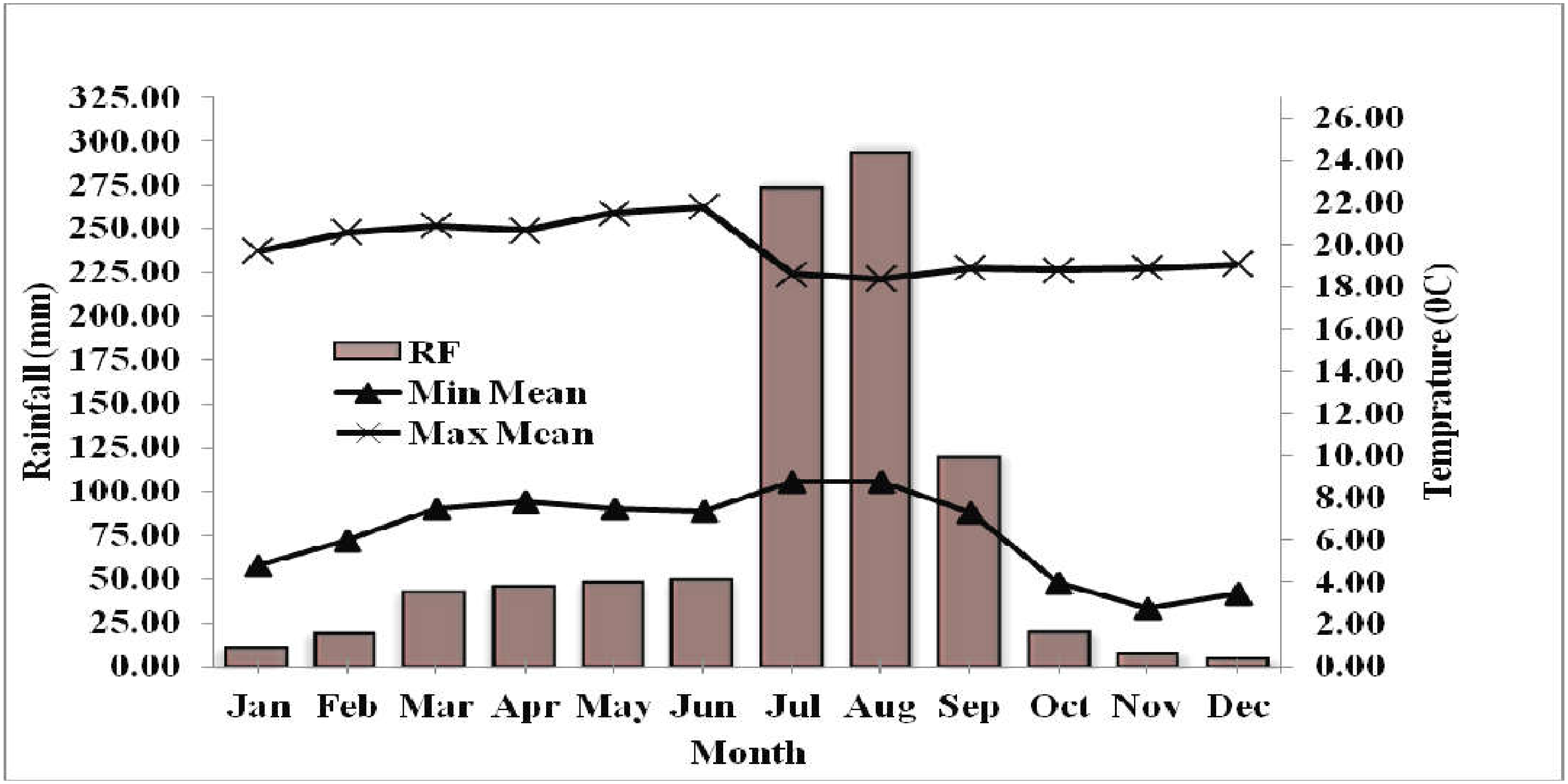
**Appendix Table 2. Long term monthly min temperature data 1985-2015, Debre Birhan Agricultural Research Meteorology Station**

| year | JAN | FEB | MAR | APRI | May | JUN | JUL | AUG | SEP | OCT | NOV | DEC | AVE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 5.3 | 4.8 | 7.0 | 7.9 | 8.1 | 7.4 | 8.3 | 8.4 | 7.0 | 4.5 | 4.3 | 4.9 | 6.5 |
| 1986 | 3.8 | 7.4 | 7.6 | 8.6 | 7.7 | 8.6 | 8.3 | 8.0 | 6.1 | 4.5 | 4.3 | 5.0 | 6.7 |
| 1987 | 5.1 | 6.9 | 8.8 | 8.0 | 8.7 | 7.7 | 8.5 | 8.9 | 7.6 | 5.5 | 4.2 | 5.2 | 7.1 |
| 1988 | 6.8 | | | 8.2 | 7.0 | 6.6 | 9.7 | 9.0 | 7.4 | 3.9 | -1.2 | 1.1 | 5.9 |
| 1989 | 0.5 | 6.2 | 7.4 | 8.0 | 5.5 | 6.3 | 8.7 | 9.2 | 9.4 | x | 1.2 | 6.7 | 6.3 |
| 1990 | 3.1 | x | x | 6.8 | 5.5 | 5.9 | 8.6 | 8.9 | 7.3 | 2.0 | 2.0 | 0.2 | 5.0 |
| 1991 | 5.3 | 6.1 | 8.4 | 7.7 | 8.1 | 7.4 | 9.0 | 8.8 | 7.1 | 1.6 | 1.8 | 0.8 | 6.0 |
| 1992 | 6.8 | 7.9 | 8.5 | 7.3 | 6.5 | 6.9 | 8.2 | 9.0 | 7.0 | 3.6 | 3.9 | 4.2 | 6.7 |
| 1993 | 5.8 | 6.9 | 5.8 | 8.2 | 6.8 | 6.5 | 8.8 | 8.6 | 7.8 | 4.5 | 1.5 | 2.5 | 6.1 |
| 1994 | 3.6 | 5.1 | 8.7 | 8.0 | 7.1 | 7.1 | 8.6 | 7.8 | 6.7 | x | 0.8 | 2.5 | 6.0 |
| 1995 | 2.8 | 7.5 | 6.7 | 8.7 | 6.4 | 6.7 | x | 9.2 | 7.0 | 2.7 | 1.1 | 5.9 | 5.9 |
| 1996 | 6.3 | 4.6 | 7.4 | 7.1 | 8.0 | 7.9 | 8.5 | 8.5 | 6.4 | 1.4 | 2.1 | 3.2 | 6.0 |
| 1997 | 6.1 | 2.2 | 8.3 | 7.0 | 6.7 | 8.5 | 8.6 | 8.1 | 7.1 | 6.1 | x | x | 6.9 |
| 1998 | 7.7 | 8.4 | 9.3 | 9.6 | 7.7 | 7.2 | 9.3 | 9.5 | 7.3 | 3.7 | -0.9 | -2.1 | 6.4 |
| 1999 | 2.2 | 3.1 | 5.9 | 5.2 | 5.8 | 6.3 | 8.6 | 8.6 | 6.2 | 4.6 | -1.2 | 1.8 | 4.8 |
| 2000 | 1.0 | 3.4 | 4.8 | 7.0 | 7.1 | 5.7 | 8.6 | 8.1 | 6.8 | 3.3 | 1.7 | 1.0 | 4.9 |
| 2001 | 1.4 | 5.0 | 8.3 | 6.0 | 8.2 | 8.0 | 9.2 | 9.2 | 6.4 | 3.3 | 2.9 | 4.6 | 6.0 |
| 2002 | 5.0 | 6.3 | 8.4 | 7.5 | 7.6 | 7.6 | 9.1 | 9.1 | 7.5 | 3.1 | 2.8 | 7.2 | 6.8 |
| 2003 | x | x | x | x | X | x | x | x | x | x | x | x | x |
| 2004 | 5.0 | 4.4 | 5.6 | 8.8 | 6.7 | 8.2 | 9.2 | 9.0 | 7.3 | 3.3 | 2.7 | 5.2 | 6.3 |
| 2005 | 5.3 | 7.1 | 8.3 | 9.2 | 9.2 | 7.9 | 9.2 | 9.2 | 8.3 | 3.9 | 2.0 | 1.7 | 6.8 |
| 2006 | 5.9 | 8.0 | 7.5 | 8.5 | 7.4 | 8.1 | 9.8 | 9.4 | 7.5 | 5.4 | 3.5 | 4.7 | 7.1 |
| 2007 | 6.6 | 7.6 | 7.7 | 8.5 | 8.1 | 8.9 | 9.5 | 9.2 | 7.5 | 3.4 | 4.0 | 1.1 | 6.8 |
| 2008 | 5.4 | 5.1 | 5.5 | 7.7 | 8.6 | 8.5 | 8.6 | 9.2 | 7.1 | 4.2 | 4.0 | 4.6 | 6.5 |
| 2009 | 6.3 | 7.6 | 8.1 | 7.4 | Xx | 8.4 | 9.2 | 9.3 | 6.5 | 4.7 | 3.1 | 7.3 | 7.1 |
| 2010 | 6.4 | 9.3 | 9.2 | 9.2 | 9.2 | 8.1 | 9.1 | 9.3 | 7.2 | 3.7 | 4.1 | 4.8 | 7.5 |
| 2011 | 6.5 | 4.6 | 7.4 | 8.8 | 7.9 | 7.6 | 8.7 | 8.7 | 7.5 | 3.4 | 4.8 | 2.0 | 6.5 |
| 2012 | 4.6 | 4.0 | 6.4 | 7.5 | 7.2 | 6.9 | 8.4 | 7.9 | 6.9 | 4.0 | 4.5 | 5.5 | 6.2 |
| 2013 | 4.7 | 6.3 | 7.9 | 7.6 | 7.7 | 7.3 | 7.9 | 8.0 | 6.9 | 5.7 | 4.6 | 1.1 | 6.3 |
| 2014 | 7.4 | 7.4 | 8.2 | 8.2 | 8.1 | 7.3 | 8.4 | 8.0 | 7.1 | 5.0 | 1.7 | 0.5 | 6.4 |
| 2015 | 2.4 | 5.6 | 6.5 | 7.3 | 8.2 | 7.4 | 6.9 | 8.3 | 10.7 | 8.0 | 10.1 | 9.4 | 7.6 |
| Ave. | 4.8 | 6.0 | 7.5 | 7.8 | 7.5 | 7.4 | 8.74 | 8.75 | 7.3 | 4.0 | 2.77 | 3.5 | 6.36 |

**Appendix Table 3. Long term monthly Max temperature data 1985-2015 ,Debre Birhan Agricultural Research Meteorology Station**

| year | JAN | FEB | MAR | APR | May | JUN | JUL | AUG | SEP | OCT | NOV | DEC | AVE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1985 | 19.4 | 19.8 | 20.4 | 18.9 | 19.7 | 21.7 | 18.7 | 18.4 | 18.2 | 18.2 | 18.6 | x | 19.3 |
| 1986 | 20.4 | 19.9 | 19.1 | 19.0 | 20.9 | 19.3 | 18.6 | 18.1 | 18.3 | 18.5 | 19.0 | 19.5 | 19.2 |
| 1987 | 19.5 | 20.9 | 19.5 | 19.7 | 19.5 | 21.9 | 22.4 | 19.5 | 19.8 | 19.5 | 19.8 | 20.1 | 20.2 |
| 1988 | 20.3 | 19.6 | 21.5 | 20.6 | 22.1 | 22.1 | 17.0 | 17.6 | 18.0 | 17.4 | 17.9 | 18.3 | 19.4 |
| 1989 | 19.0 | 18.5 | 19.7 | 18.1 | 20.5 | 21.4 | 18.8 | 18.3 | 18.2 | 18.0 | x | x | 19.1 |
| 1990 | 19.0 | x | x | 20.1 | 22.6 | 23.0 | 18.6 | 18.9 | 18.4 | 18.2 | 18.5 | 18.8 | 19.6 |
| 1991 | 19.9 | 20.1 | 20.6 | 20.8 | 22.0 | 22.5 | 18.0 | 17.8 | 19.0 | 18.2 | 18.6 | 18.3 | 19.7 |
| 1992 | 18.1 | 18.9 | 21.7 | 21.5 | 21.6 | 22.6 | 18.3 | 16.6 | 17.5 | 17.3 | 17.3 | 18.7 | 19.2 |
| 1993 | 18.9 | 18.7 | 20.6 | 19.4 | 19.9 | 21.9 | 18.5 | 18.9 | 18.4 | 18.0 | 18.2 | 18.9 | 19.2 |
| 1994 | 19.7 | 20.9 | 20.4 | 21.5 | 22.0 | 21.4 | 17.4 | 17.6 | 18.1 | x | 19.3 | 19.8 | 19.8 |
| 1995 | 20.2 | 20.8 | 21.3 | 20.8 | 22.1 | 23.4 | x | 18.7 | 19.4 | 19.2 | 19.8 | 19.7 | 20.5 |
| 1996 | 19.1 | 21.8 | 20.7 | 21.3 | 20.1 | 19.2 | 18.5 | 18.6 | 19.6 | 18.9 | 18.7 | 18.4 | 19.6 |
| 1997 | 19.2 | 20.1 | 21.2 | 19.8 | 21.4 | 21.1 | 18.0 | 18.3 | 19.3 | 18.3 | x | x | 19.7 |
| 1998 | 19.8 | 21.0 | 20.9 | 22.2 | 22.4 | 23.3 | 17.8 | 17.7 | 18.7 | 18.6 | 18.4 | 18.4 | 19.9 |
| 1999 | 19.3 | 21.5 | 20.5 | 21.8 | 22.6 | 22.4 | 17.1 | 18.1 | 18.6 | 17.9 | 17.8 | 18.6 | 19.7 |
| 2000 | 19.7 | 20.5 | 21.5 | 20.8 | 21.8 | 22.7 | 18.3 | 17.7 | 18.5 | 18.4 | 18.5 | 19.4 | 19.8 |
| 2001 | 19.9 | 20.8 | 19.2 | 21.2 | 22.2 | 21.5 | 17.9 | 17.6 | 19.6 | 19.9 | 19.6 | 19.3 | 19.9 |
| 2002 | 19.5 | 21.3 | 20.7 | 21.4 | 23.0 | 22.8 | 21.5 | 18.1 | 18.4 | 19.6 | 19.8 | 19.3 | 20.5 |
| 2003 | x | x | x | x | x | x | x | X | x | x | x | x | x |
| 2004 | 20.8 | 20.4 | 21.0 | 20.4 | 23.1 | 21.2 | 18.7 | 18.7 | 19.2 | 18.6 | 19.5 | 19.6 | 20.1 |
| 2005 | 20.1 | 22.1 | 22.0 | 21.3 | 20.4 | 21.6 | 18.3 | Xx | xx | xx | xx | xx | 20.8 |
| 2006 | 20.0 | 21.0 | 20.4 | 20.0 | 21.9 | 22.6 | 19.0 | 18.0 | 18.6 | 19.6 | 18.2 | 19.1 | 19.9 |
| 2007 | 19.9 | 20.6 | 21.8 | 20.0 | 22.7 | 21.2 | 17.8 | 18.3 | 18.8 | xx | 18.6 | 18.7 | 19.9 |
| 2008 | 20.0 | 20.3 | 22.0 | 20.8 | 21.3 | 21.1 | 18.9 | 19.0 | 19.4 | 19.2 | 18.4 | 18.8 | 19.9 |
| 2009 | 19.3 | 20.3 | 21.5 | 21.7 | xx | 23.7 | 17.9 | 18.7 | 19.6 | 19.0 | 19.7 | 18.5 | 20.0 |
| 2010 | 19.8 | 20.9 | 20.4 | 20.8 | 21.3 | 22.7 | 18.7 | 18.1 | 19.0 | 19.8 | 19.2 | 19.2 | 20.0 |
| 2011 | 19.5 | 21.6 | 20.1 | 21.9 | 21.2 | 19.3 | 18.1 | 18.7 | 18.8 | 19.4 | 19.4 | 19.4 | 19.8 |
| 2012 | 19.5 | 20.5 | 21.7 | 20.2 | 21.3 | 21.2 | 18.4 | 19.8 | 21.0 | 21.5 | 20.2 | 19.8 | 20.4 |
| 2013 | 20.1 | 21.2 | 22.0 | 21.4 | 20.8 | 21.3 | 17.7 | 17.3 | 18.6 | 18.2 | 19.9 | 19.5 | 19.8 |
| 2014 | 19.9 | 20.4 | 20.8 | 20.5 | 20.9 | 21.3 | 18.8 | 18.0 | 18.1 | 18.1 | 18.5 | 18.6 | 19.5 |
| 2015 | 20.1 | 21.8 | 22.5 | 23.4 | 23.3 | 21.7 | 21.6 | 21.6 | 20.2 | 20.4 | 20.1 | 20.1 | 21.4 |
| Ave. | 19.7 | 20.6 | 20.9 | 20.7 | 21.5 | 21.8 | 18.6 | 18.4 | 18.9 | 18.8 | 18.9 | 19.1 | 19.82 |

**Appendix Table 4: Monthly Rainfall means, monthly minimum and maximum temperature of the study area**


325.00
300.00
275.00
250.00
225.00
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
Rainfall (mm)
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Temprature (0C)
RF
Min Mean
Max Mean
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

**Appendix 5:** Assessment of late blight severity under field conditions (%) (Henfling, 1987).

| Phytophthora infestans *(%)* Average | Boundaries | Symptoms |
|---|---|---|
| 0 | 0 | *P. infestans* not observed |
| 2.5 | Trace < 5 | *P. infestans* present. Maximum 10 injuries per plant |
| 10 | 5 < 15 | Plants seem to be healthy, but injuries can be easily observed. There are no more than 20 affected leaves |
| 25 | 15< 35 | *P. infestans* is easily observed on the plants. About 25% of the leaf area is affected. |
| 50 | 35< 65 | Plants look green, but each one is affected by the pathogen, lower leaves are necrotic. About 50% of the leaf area is destroyed. |
| 75 | 65< 85 | Plants look green with brown spots. About 75% of the leaf area is affected. Leaves in the middle of the plant are destroyed |
| 90 | 85< 95 | Only upper leaves are green. Most of leaves are affected and many stems have externalinjuries |
| 97.5 | 95< 100 | Plants look brown, a few upper leaves are green and most of the stems are affected or dead |
| 100 | | Leaves and stems are destroyed |

# BIOGRAPHICAL SKETCH

Abdu Yassin was born in March 13, 1984 at Haik town, South Wollo Zone, Amhara National Regional state, Ethiopia.He attended his elementary education from 1990 to 1995 at Haik kutir Hulet (Kete) elementary School. The author joinedSecondary education from 1996 to 2001 at Haik Junior and senior secondary School.

He joined Ambo College of Agriculture in 2002 and graduated with a diploma in General Agriculture in July 2003. One year later after graduation, he was employed by the Amhara Regional Agricultural Research Institute at Debrebirhan Agricultural Research Center as a Technical Assistance and Site Manager at Ankober and Menz Lallo Wereda Research sites, where he worked for three years. He again joined Haramaya University in 2007 to pursue a study leading to the Degree of Bachelor of Sciences, and graduated with a BSc Degree in Plant Sciences in September 2011. He was then employed at Debrebirhan Agricultural Research Center as an Assistance Researcher in Horticultural Crops Case team, where he rendered his services for five years. He joined Hawassa University in October 2016 to pursue a study leading to the Degree of Master of Sciences in Horticulture.