CHARACTERIZATION OF POTATO (*SOLANUM TUBEROSUM* L.) CULTIVARS GROWN IN ERITREA USING MORPHOLOGICAL, MOLECULAR AND NUTRITIONAL DESCRIPTORS

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Characterization of Potato (*Solanum tuberosum* L.) Cultivars Grown in Eritrea Using Morphological, Molecular and Nutritional Descriptors

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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DEDICATION

I dedicate this research work to my beloved family**:** My wife**, Selamawit Tesfay** and our children, **Fiona, Luna and Bruk** for their continuous and unreserved support throughout this study work.

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ABBREVIATIONS AND ACRONYMS

2, 6 DCIP	2, 6-dichloroindophenol
AAS	Atomic Absorption Spectrophotometer
AFLP	Amplified Fragment Length Polymorphism
AMOVA	Analysis of Molecular Variance
ANOVA	Analysis of Variance
ASARECA	Association for Strengthening Agricultural Research in Eastern and
BecA	Biosciences eastern and central Africa
bp	base-pair
BSA	Bovine Serum Albumin
CIP	International Potato Center
cm	centimeter
CTAB	Cetyltrimethylammoniumbromide
DAP	Di-ammonium Phosphate
DaP	Days after Planting.
DNA	deoxyribonucleic acid
DWB	dry weight basis
EDTA	ethylenediaminetetraacetic acid
FAO	Food and Agriculture Organization
FAOSTAT	FAO Statistical Databases
FWB	fresh weight basis
FYM	farmyard manure
GOE	Government of Eritrea
HAC	Hamelmalo Agricultural College
HPLC	high pressure liquid chromatography
JKUAT	Jomo Kenyatta University of Agriculture and Technology
LSD	Least significant difference
m.a.s.l	Meter above sea level
$MgCl_2$	Magnesium Chloride
MoA	Ministry of Agriculture
NARI	National Agricultural Research Institute
NEPAD	New partnership for Africa's Development

ng	Nano gram
NGO	Non-governmental organization
PCA	Principal Component Analysis
PCoA	Principle Coordinate Analysis
PCR	Polymerase Chain Reaction
pH	negative logarithm of hydrogen ion concentration
PIC	Polymorphism Information Content
PRA	Participatory Rural Appraisal
PTM	Potato Tuber Moth
RAPD	Random Amplified Polymorphic DNA
RNaseA	Ribonuclease A
SDS	Sodium Dodecyl Sulfate
SPSS	Statistical Package for Social Services
SSR	Simple Sequence Repeat
t/ha	Tones per hectare
TAE	tris-acetate
TE	tris EDTA
THF	Tetrahydrofuran
Tris	Tris (hydroxym ethyl) aminomethane
TSS	Total Soluble Solids
UNICEF	United Nations Children's Emergency Fund
UPGMA	Unweighted Pair-Group Method using Arithmetic Averages
USDA	U.S. Department of Agriculture
UV	Ultraviolet
UV-VIS	Ultra-Violate Visible light spectrophotometer
µg	microgram
µL	microliter

GENERAL ABSTRACT

Potato is one of the most important and widely grown vegetable crops in Eritrea. The crop contributes to food security directly as a food source and also as a cash crop. There is limited information in the country that could be utilized for enhancing productivity. The main objective of this study was to document existing potato production practices, and to assess diversity among potato cultivars grown by farmers using morphological, molecular and nutritional traits. Information on the existing potato production practices was obtained from the farmers through a diagnostic survey using a semi-structured questionnaire and focus group discussion. Useful information, on farming practices and major constraints were collected. The results indicated that there were variations on the farming practices and cultivars grown between the two Zobas (counties) surveyed. Majority of the respondents faced challenges in obtaining farm inputs especially quality seeds (91%), fertilizers (87%) and pesticides (90%). As a result most farmers kept their own harvest for use as seed in the following season. Moreover, pest incidence particularly, late blight infection (97%) and cut worm infestation (87%) were reported in all the visited villages posing major problem to farmers. Twenty one cultivars were characterized using 33 agro-morphological descriptors. The bi-plot analysis classified the materials into four groups while the Unweighted Pair Groups Method with Arithmetic mean (UPGMA) clustering grouped them in to three where G-II and G-III were merged together at 92% Euclidean similarity level. The grouping helped to identify materials that share the same characteristics and/or that are closely related and *vice versa.* It was noted that there was no distinct relationship between the cluster groups and geographic origin of the materials. In addition, farmers' cultivars sharing the same name could be grouped in different clusters. The molecular characterization was conducted using 12 SSR markers. A total of 91 alleles were amplified with an average of 8 alleles per marker. All of the farmers' cultivars from Eritrea were clearly distinct from each other showing high genetic diversity as explained by the diversity index (h). Potato cultivars from Eritrea appeared to cluster separately from the other check

samples from Kenya and Rwanda, which reflect a contribution from the tuberosum germplasm prominent in temperate regions. Analysis of raw and boiled farmers' potato cultivars for nutritional traits indicated wide variations among themselves. Some of the cultivars exhibited higher values for protein (47%), dry matter content (60%) and phosphorus (40%) than their mean average. Boiling significantly ($p<0.001$) reduced the levels for most of the nutritional traits. Results on characterization of the potato cultivars grown in the country using morphological, molecular, as well as nutritional traits indicated that the materials were diverse and contained traits of interest which could be exploited in future breeding program.

CHAPTER ONE

INTRODUCTION

1.1 Background

Potato belongs to the family, *Solanaceae* (*Solanum tuberosum* L.), and is one of the most important vegetable crops grown throughout the temperate and tropical regions of the world. Globally, the crop ranks fourth in importance, following wheat, maize and rice (Pandey, 2008). However, it ranks first among the world's root crops, thus, remaining a priority non-cereal crop in many, especially developing countries. Potato is cultivated for its nutritional, medicinal and industrial values. It is a healthy and nutritious crop providing no fat, no cholesterol and no sodium while providing more potassium and less calories than many other crops (Haytowitz *et al*., 2011). It can be eaten boiled, roasted, baked or fried and is processed into a very wide range of products. The tubers are also fed fresh to cattle and sheep or are stored as silage and used in the form of meal.

There are about 2000 species of *Solanum*, but only S. *tuberosum* is extensively grown as a food crop throughout the world. Even though most of the ware potato produced belong to one single species with a few varieties, estimates suggest that there exist approximately 6, 500 potato varieties worldwide (International Potato Center [CIP] 2006a). According to Lutaladio, Haverkort, Ortiz, & Caldiz (2009) potato genetic resources include wild relatives, native cultivar groups, local farmer-developed varieties ("landraces"), and hybrids of cultivated and wild plants. Today potato plays a significant role in human nutrition world-wide with more than 320 million tons of ware potato produced annually on 20 million hectares of land (Food and Agriculture Organization [FAO] 2011; Poczai *et al*. 2010); with an average yield of 16 t/ha (AgriWatch, 2012; Pandey, 2008). Its production in the developing world, for instance, grew from 85 million tons in1991 to 165 million tons in 2007 (Lutaladio *et al*., 2009).

Equally, its consumption is accelerating in most of the developing countries (AgriWatch, 2012). The importance of potato in developing countries could be attributed to the fact that it produces more edible energy and protein per unit area and time than other food crops, and secondly, the crop fits well into multiple cropping systems prevalent in tropical and subtropical agro-climatic conditions (Badoni & Chauhan 2009; Fernie & Willmitzer 2001). It is among the most efficient commodities for converting natural resources, labor and capital into a high quality food (Association for Strengthening Agricultural Research in Eastern and Central Africa [ASARECA] 2009). This makes it an essential asset of crop, considering the increasing population pressure necessitating intensification of food production (Gildemacher, 2012).

1.1.1 Potato production in Africa

The potato crop arrived in Africa around the turn of the 20th century (FAOSTAT, 2008) by colonist mostly from Europe. The crop is cultivated in most countries of the continent. It grows under varying conditions ranging from irrigated commercial farms in Egypt and South Africa to intensively cultivated tropical highland zones of Eastern and Central Africa, where it is mainly a small scale farmer's crop (Cromme, Prakash, Lutaladio, & Ezeta, 2010). In the Eastern and Central Africa region, potato is one of the most important food security crops consumed by a large proportion of the population (Tesfaye *et al*., 2010).

In the past few years, potato production in Africa has been in continual expansion rising from 2 million tons in 1960 to a record 16.7 million tons in 2007 (FAOSTAT, 2008). The crop is increasingly becoming a favored food in urban areas (ASARECA 2009). Likewise, the production in Sub-Saharan Africa (SSA) has more than doubled since 1994, with 70% of that growth concentrated in eastern Africa (Cromme *et al*., 2010). Potato is directly consumed as a food and is also a cash crop to the people of this region. Although, the current per capita potato consumption levels in Sub-Saharan

Africa are still low, its trend shows that it is growing steadily (Gildemacher, 2012). This is ascribed to the fast population growth and increased urbanization.

1.1.2 Potato production in Eritrea

Eritrea is a country located in the horn of Africa, bordered by Sudan in the northwest and west, Ethiopia in the South, Djibouti in the Southeast and Red sea in the East and Northeast lying between latitudes 12° and 18°N, and longitudes 36° and 44°E (Figure 1.1). The country has a total land area of 12.1 million ha and a population of 6 million (UNICEF, 2012). It has a high central plateau that varies from 1,800 to 3,000 meters above sea level (m.a.s.l). The climate ranges from hot; dry desert strip along the Red Sea coast; cooler and wetter in the central highlands; to semiarid in the western hills and lowlands. Heavy rainfall occurs usually during the summer season (June–September) while in the coastal areas, rainfalls between December and February.

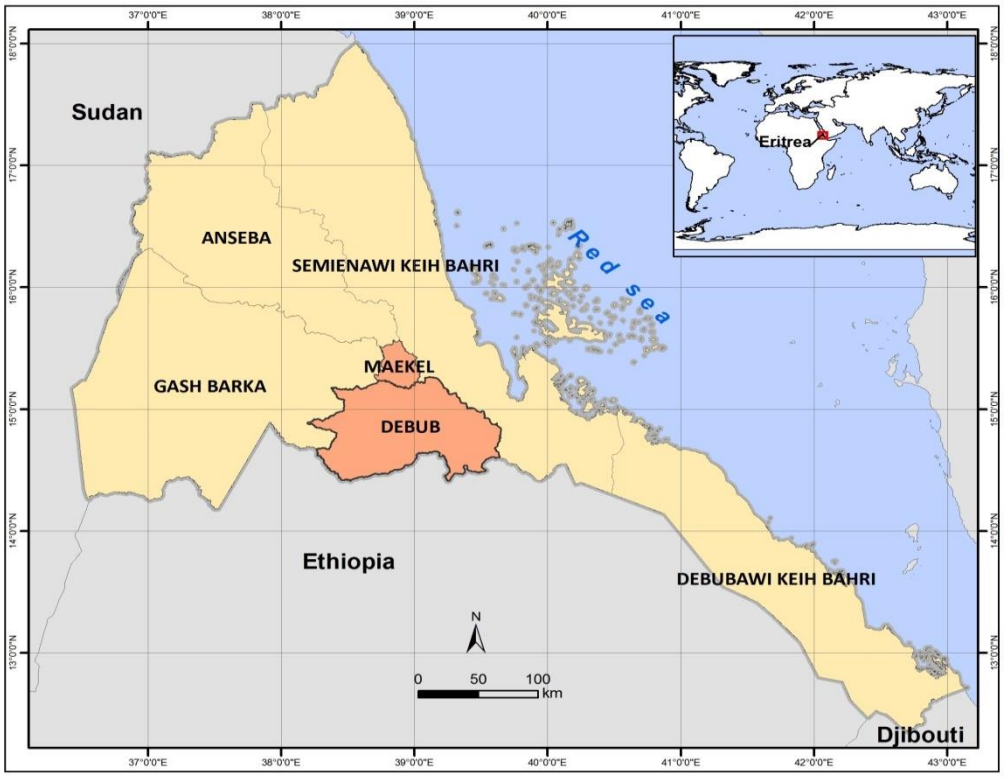

Figure 1.1: Map of Eritrea, along with its neighbouring countries (Courtesy: Selam Tesfay, 2014).

Over 70 % of the Eritrean population lives in rural areas and relies on subsistence agriculture (NEPAD & FAO, 2005). Potato is one of the most important and widely grown crops in the country, thus contributing to food security either directly as a food or as a source of income. The country has a long history of growing potato crop. The bulk of production occurs in the central highlands (Zoba Maekel and Zoba Debub) with a limited amount coming from Zoba Anseba and Zoba Semenawi Keyh Bahri (Bereketsahay, 2000). Data from the Ministry of Agriculture [MoA] in the year of 2011 estimated that the total land under potato cultivation was 2,357 ha with an average yield of 11 ton/ha (Figure 1.2).

Potato cultivation is predominantly by smallholder farmers with traditional systems of low input low output system in an average land holding of less than 1ha for most farmers. Since there is no private potato seed supply scheme in the country, the MoA, in collaboration with its partners, has in the past been importing potato seeds from abroad ever since the inception of the country (1991) to be distributed to farmers. To that effect, potato seeds have been imported from Italy, Holland, Ethiopia, UK for varieties such as *white and red kara, Diamond, Spunta, Ajiba, Desiree, Kondor, Cosmos, Picasso, Zafira* (MoA unpublished data). The *White* and *Red Kara* varieties were imported from Holland in 1993 and in 1994 the *Diamond* variety was imported from Italy. The varieties performed well upon their arrival but there was low preference for *Red Kara* by consumers owing to its color. The variety *Spunta* was imported from Holland in 2000 and it has remained as a farmer-preferred variety to date. In 2002, the MoA in collaboration with Danish International Development Agency (DANIDA) imported foundation and certified varieties of *Ajiba* and *Desiree.* In 2003, the Emergency Rehabilitation Program (ERP) imported three varieties (*Timate, Farmer* and *Ajiba*) varieties from Holland for the same objective. In 2008 and 2009 the Zoba Debub administration imported *Ajiba* and *Spunta* from Holland funded by Care International and/or Oxfam, UK. Importation and distribution of potato seeds to farmers are frequently practiced to address the acute shortage of quality seeds.

Potato production in Eritrea is practiced both under rain-fed and irrigated systems. Irrigated farming is practiced by farmers residing near dams and rivers. Rain-fed production occurs in the central highlands of Eritrea where there are two distinct potato growing seasons. The long rainy season "*kremti*" that extends from June to September which is characterized by high rain fall with the optimum planting date being the first week of June. For the off season, farmers start planting in autumn and/or spring. The second rainy season, predominantly, in Northern Red sea zone "*kiremtibahri*", extends from October to December (Bereketsahay, 2000). Between the months of December and January there is a risk of frost in which case farmers do not grow potato.

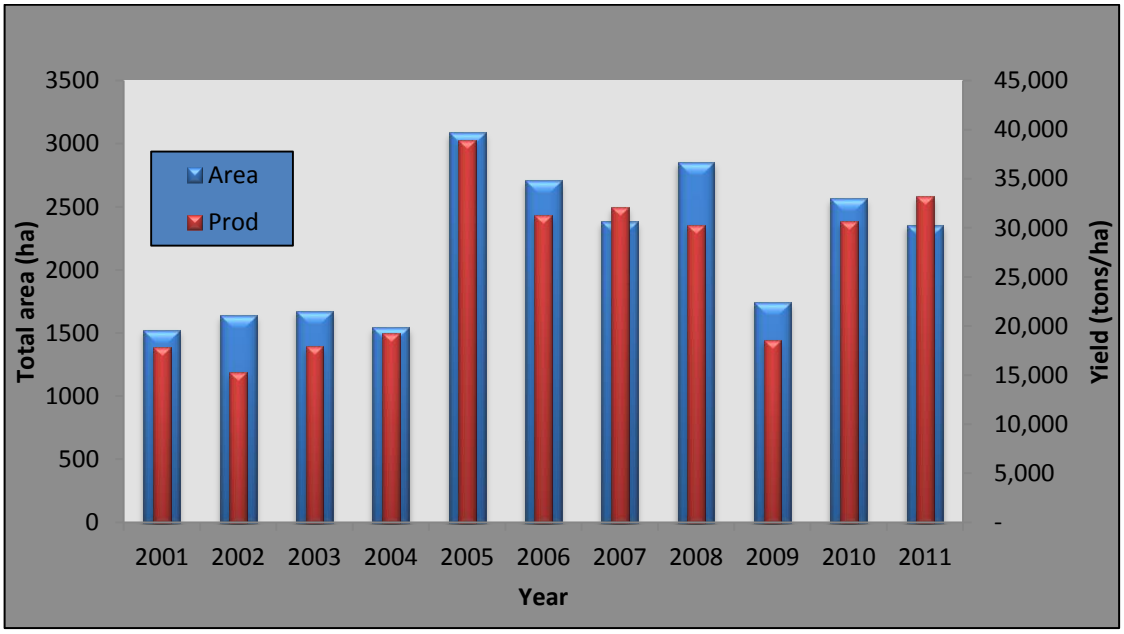

Figure 1.2: Total potato production and area under cultivation in Eritrea (2001-2011) (Source: MoA, 2011).

1.2 Statement of the problem

Potato is one of the priority crops selected to ensure food self-sufficiency in Eritrea. Demand for potato has been going up at a rate higher than the supply thereby causing a severe gap in the market. The acute shortage of supply resulted in chronic malnutrition

and food insecurity in the country. In the absence of invaluable documented data on the overall production systems of potato including major constraints and potentials, area under cultivation, varietal performance, spatial varieties and pest prevalence made it difficult to understand the real problem and equally hard to plan any meaningful strategy for intervention to cause impact and boost-up the supply.

Moreover, very little effort has been done so far to identify and characterize the potato cultivars grown in the country. As a result, identification remains a major problem not only to farmers, but also to the scientific community. The unimproved cultivars are widely known by names given by the local farmers on the basis of their flower colour as white, pink and yellow flowered or after their place of origin/cultivation as *carneshim*, *Israel, shashmenie, Asela, America*. This makes it difficult and complicated to collect, conserve and utilize potato germplasm in the country and/or design crop improvement strategy to meet the demand. Yet, the nutrirional contnet of the cuntivars grown in the country has never been assessed, thus, their contribution in meeting the nutritional supply is not known.

1.3 Justification

Given the pivotal importance of potato and lack of relevant information and data, a holistic approach to generate baseline information on current potato production practices and to understand the major potentials and constraints, is of paramount importance. Diagnostic survey helps to generate baseline information which in turn will elucidate the situtation on the ground to formulate technical intervention mechanism. The finding will also provide valuable resource information to understand and address major potato production constraints and thus pave way for its improvement.

Identification of individual varieties using morphological and molecular markers is necessary in understanding and determining their genetic distinctness. Traditionally, crop identification and improvement strategies have been achieved using morphological

descriptors, in recent years advances in molecular techniques have also provided the tools that enable the study of variability at the DNA level. To that extent, both morphological and molecular techniques have to be applied in order to correctly identify potato cultivars and to assess their diversity and similarity. Equally, intensive nutritional assessment is important to identify suitable cultivars for a particular utilization. The finding will undoubtedly be useful for breeders while designing crop improvement program as well as policy makers while making decisions on food security.

Similar studies on potato have been conducted in Kenya (Abong, Okoth, Karuri, Kabira, & Mathooko, 2009; Muthoni, Shimelis, & Melis, 2014); Rwanda (Muhinyuza *et al*., 2015); Nigeria (Odebunmi, E. O., Oluwaniyi, O. O., Sanda, A. M., & Kolade, 2007); South Africa (Katundu, Hendriks, Bower, & Siwela, 2007); Turkey (Arslanoglu, Aytac, & Oner, 2011); Iran (Felenji, Aharizad, Afsharmanesh, & Ahmadizadeh, 2011); India (Chimote, Pattanayak, & Naik, 2007) and China (Liao & Guo, 2014). Although potato has been under cultivation for a long time and is economically important in Eritrea, no such studies have been conducted. The fact that potato is highly consumed staple food, in Eritrea, any effort to change/improve the nutritional quality will impact significantly on combating malnutrition. Thus the current study is proposed to address the issue so that to achieve food security and ensure well-being of growers and consumers.

1.4 Research Objectives

1.4.1 General objective

The overall objective of the current study was to contribute to increased potato production and thereby enhance food security and nutrition supply in Eritrea through morphological, molecular and nutritional characterization.

1.4.2 Specific objectives:

- ✓ To document and compare potato cultivation practices in two agricultural zones of Eritrea
- ✓ To characterize potato cultivars grown in Eritrea using morphological descriptors.
- ✓ To evaluate genetic diversity within the local farmers' and imported potato cultivars using molecular markers.
- ✓ To assess selected farmers' cultivars for their yield and nutritional content.

1.5 Null Hypothesis

- ✓ The potato farming practices and cultivars used are not different in the two agricultural zones studied.
- ✓ There are no morphological differences among the farmer's and imported potato cultivars grown in Eritrea.
- ✓ Local farmer' and imported potato cultivars grown in Eritrea are not genetically different from each other.
- ✓ There are no difference in yield and nutritional content among farmers' potato cultivars grown in Eritrea**.**

CHAPTER TWO

LITERATURE REVIEW

2.1 Potato botanical description

Detailed botanical and morphological description of potato crop was reported by Huaman (1986). Potato is an annual plant that produces edible underground mature tubers that are used as vegetable (Struik & Wiersema, 2001). It is herbaceous plant from the *Solanaceae* family, with a basic set of 12 chromosomes (x = 12). It belongs to the genus *Solanum,* which presents species with different ploidy levels, varying from diploid (2n = 24) to hexaploid (6n = 72). *Solanum tuberosum* L., which is tetraploid (4n=48), is the most commonly cultivated species (Rosa *et al*., 2010). The latest classification suggests there are only four cultivated species: *S. tuberosum, S. ajanhuiri*, *S. juzepczukii* and *S. curtilobum* (Spooner *et al*., 2007), however seven species were identified previously by Hawkes (1990). However, *S. tuberosum* is by far the most dominant and widely grown. The roots are fibrous and the tubers arise separately on stolons from the main underground shoot system. The stem is angular, branched and bears compound, alternate leaves up to 30 cm long. The flowers produced in clusters or cymes are yellow, white, red, blue, pink or purple with yellow stamens, but are rarely produced under conditions in which day lengths are short and temperatures are high. The fruits are globular berries and contain poisonous alkaloids (*Solanine*) (Rice, Rice, & Tindall, 1990). In general, the tubers of varieties with white flowers have white skins, while those varieties with colored flowers tend to have pinkish skins (Winch, 2006). Potato is cross-pollinated mostly by insects including bumblebees which carry pollen from other potato plants, but a substantial amount of self-fertilization occurs as well. Potato varieties can be propagated vegetatively by planting tubers, pieces of tubers cut to include at least one or two eyes and "true seeds" or botanical seeds.

2.2 Potato Production

Its estimated that worldwide there is more than 320 million tonnes of potato cultivated annually on about 20 million hectares of land (Cromme *et al*., 2010; Haan & Rodriguez, 2016). This ranks the potato at number four among the worlds' most important staple food crops. The crop was first cultivated in South America between three and seven thousand years ago after which it was spread to the rest of the world (Figure 2.1). Western South America is the primary center of the origin and diversity of the potato crop and its wild relatives (Haan & Rodriguez, 2016). China is now the biggest potato producer, and almost a third of all potatoes is harvested in China and India (Table 2.1). Whereas the top African countries are Egypt, South Africa, Algeria, and Morocco in that order producing more than 80% of all the potatoes in the continent. The recent analysis indicated that potato consumption and production has been increasing across the developing world. According to Haan and Rodriguez (2016) the potato production has rapidly overtaken all other food crops in Africa and Asia since the early 1960s. Despite this increase, however, the trend is not observed in all low- and middle-income countries where potato is an important staple, the authors added.

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Table 2.1: Top five world potato producers (FAOSTAT, 2015)

Country	Potato production 2013 (metric tonnes)	% of World total
China	95,941,500 m/t	25.4%
India	45,343,600 m/t	12.0%
Russian Federation	30,199,126 m/t	8.0%
Ukraine	22,258,600 m/t	5.9%
United States	19,843,919 m/t	5.2%

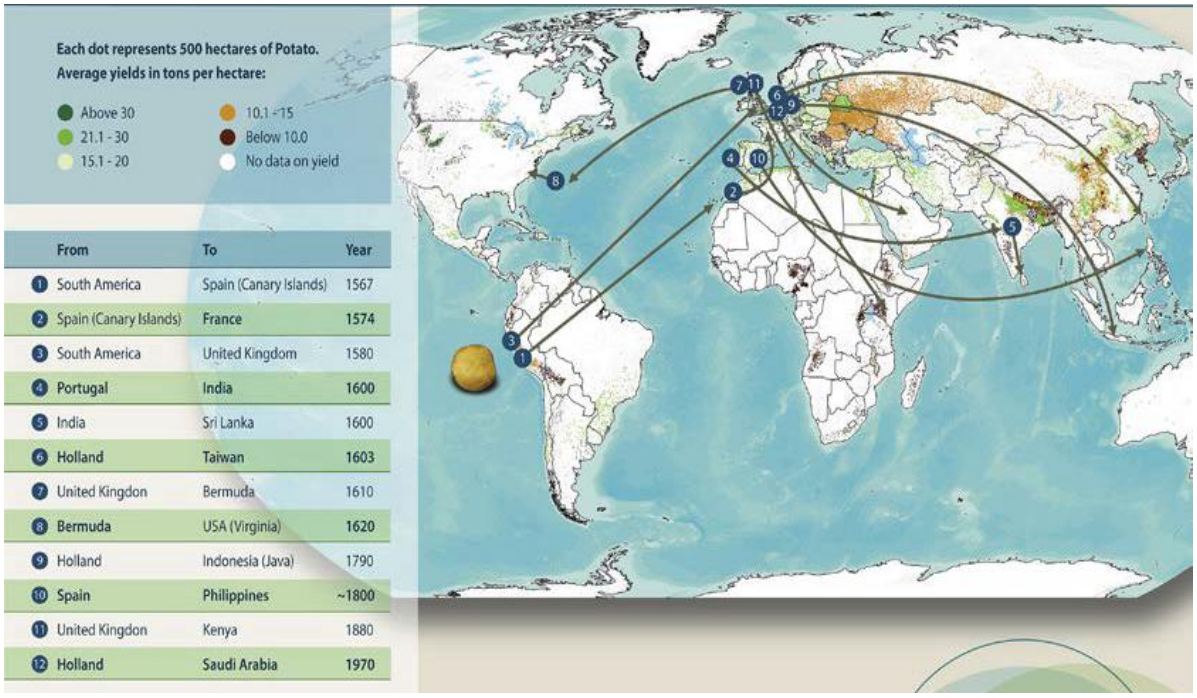


Figure 2.1: The spread of potato around the world from Peru (Haan & Rodriguez, 2016)

Potato plants are herbaceous perennials that grow about 60 cm (24 in) high, depending on variety, the culms dying back after flowering (Winch, 2006). If grown from seed tubers, it goes through five phenophases: sprout development stage, vegetative growth stage, tuber initiation stage, tuber bulking stage and finally the maturation stage Rowe (as cited in Otroshy, 2006). The global average potato yield is 16-18 metric tons per hectare (t/ha). The yield gap is particularly high in Africa, where average yields are 14.2 t/ha (Haan & Rodriguez, 2016). The major constraint of potato production in most regions is the inadequate supply of reasonably priced, good quality seed potato of the desired varieties. Seed potato is usually the most expensive input in potato cultivation, accounting for 40 to 50 percent of the production cost (Pandey, 2008). The high cost has been attributed to the fact that seed potatoes are bulky and their multiplication rate is low. Consequently, most small scale farmers cannot afford the high prices of seeds. According to Dawson (2012) most potato farmers commonly use small tubers from a previous crop as seed. In Kenya, for instance, farmers almost solely depend on informal

seed sources (farm-saved, local markets or neighbours) (Muthoni & Nyamongo, 2009). This exacerbates the spread of seed-borne diseases especially bacterial wilt and viruses that leads to increased levels of disease in a seed-line, a phenomenon known as seed degeneration. Such materials are of poor quality and commonly succumb to disease infestation thereby giving low yields.

Variations in potential yield among growing seasons, sites, varieties, seed source and management practices are large. It is useful to explain these variations and explore possibilities of increasing land under cultivation in certain areas (Caldiz, 2000). In most countries the harvested yield is not completely marketable. Farmers are expected to deliver potatoes "field sorted", i.e. to make a first rough sorting, removal of stones, rotten potatoes, etc., (Janssens, Smit, & Buurma, 2004). High cost of inputs especially seeds, fungicides and fertilizers greatly limit the production of ware potatoes in Kenya (Kaguongo *et al*., 2008) cited in (Muthoni & Nyamongo, 2009). This leads to under application of fungicides and fertilizers and coupled with poor quality seeds, the net returns to the farmer are minimal. Post-harvest losses due to pests and diseases are experienced by a large proportion of farmers. The extent of losses are estimated between 5 and 10% but reach up to 100% in extreme cases even in the developed European countries (Tamm, Smith, Philips, & Hospers, 2004). The proportion of marketable yield varied from less than 40% to 100% in the best cases according to the same authors.

2.3 Varieties

The potato crop has been bred into many standard or well-known varieties, each of which has particular agricultural or culinary attributes. Close to 4,000 different varieties have been reported from various countries (Rosa *et al*., 2010). In general, varieties are categorized into a few main groups, such as russets, reds, whites, yellows and purples based on common characteristics. The widely cultivated tetraploid species, *S.*

tuberosum Chilotanum group ($2n = 4x = 48$) is believed to have contributed to the most of the European and North American gene pool and global crop improvement (Haan & Rodriguez, 2016). The choice of the varieties for any given locality should be made upon the basis of factors such as soil type, average growing season temperature and market preference (Janssens *et al*., 2004). For a variety to be popular on most markets today, it must have white skinned tubers with few, shallow eyes and the tubers must be rather short, flat and of high starch content (Wolfe & Kipps, 2004).

2.4 Seed quality

Seed quality is an extremely important factor for potato production and the use of certified seed has been advocated in most potato growing regions of the world (Meybodi, Mozafari, Babaeiyan, & Rahimian, 2011).

Quality indicators of potato seed have two dimensions: the biological attributes (biological quality) and the appearance attributes (commercial quality) (Pandey, 2008). Biological quality is crucial for productivity, whereas commercial quality is mainly for market value. The biological quality, furthermore, can be expressed by the level of disease infection and the physiological age of seed tubers. It is well known that seed tubers planted continuously for several years will show degeneration. The average yield increase from the use of good quality seeds ranges between 30 to 50 percent compared to farmers' seeds (Pandey, 2008). Due to this fact, it is necessary to use quality and new seeds to avoid continuous degradation and disease spread.

2.5 The study approaches

2.5.1 The survey

A holistic approach survey on potato cultivation systems helps not only to elucidate the circumstances but also the potentials and constraints; hence a design can be formulated

to improve the condition. According to Kadian *et al*. (2010) the survey on potato in India helped to study existing potato production systems and agroecologies in order to develop a comprehensive work plan for improving food security and livelihood of poor farmers further through enhanced potato productivity. Moreover, the Participatory Rural Appraisal (PRA) is an approach used to involve focus groups representing the growers to share, enhance and analyze their knowledge of farming and conditions and plan of action (Chambers, 1994). Participatory Rural Appraisal techniques (PRAs) are a range of survey methods to be used principally in the extraction of qualitative data (Davis, 2001) that could not be captured by ordinary questionnaires. The approach is described as a tool allowing local people to use their own means and ways to express themselves freely and design a solution within their system. It is widely used method in most of the east African countries (Chambers, 1994).

2.5.2 Morphological and Molecular characterization

The identification of individual varieties is important at every stage of their production, breeding, registration, seed-production, and testing processes to determine distinctness of plants (Nováková, Šimáčková, Bárta, & Čurn, 2010). A number of methods are currently available including pedigree data, morphological data, agronomic performance data, biochemical data, and molecular (DNA based) data (Mohammadi & Prasanna, 2003). The traditional approach of variety identification is composed of the observation and the recording of morphological characters or descriptors (Nováková *et al*., 2010).

Morphological descriptors for potato consist of 50 characters, 12 of which are concerned with sprouting, along with a series of agronomic characters such as plant height, leaf size and various features of the flowers and tubers. Such an approach is commonly applied by various authors and is undoubtedly successful in the process of Distinctness, Uniformity and Stability (DUS) testing (Nováková *et al*., 2010). For example, Solis *et al*, (2007) used morphological data to separate potato cultivars into

different groups using clusters analysis. According to the authors, the cultivars clustered into 2 major groups, whereby the first group included potato cultivars with semi late vegetative phase and elongate tubers, and dark purple skin. The stems of this group present angular sections and green colours and node of reddish and purple colours. The second group had semi early vegetative phase and tubers of round forms, with skins principally purple colour and secondary white colour, distributed through all tuber or located around the eyes. The sole use of morphological characters to characterize potato varieties is, however, not always consistent and accurate thus, misleading. It is less suitable when results are required rapidly, such as for the identification of tuber materials. The characters are analyzed during different developmental stages, which are time-consuming and can be highly influenced by environmental factors (Rosa *et al*., 2010). Furthermore, morphological characters are often multigenic, continuously expressed and influenced by environmental interactions, making it difficult to assess them quickly and objectively, and requiring replication of observation Mba and Thome (as cited in Nováková *et al*. 2010). Moreover, according to Solis *et al*. (2007) the Mantel Test showed a very low correlation (r = - 0.09) between the morphological and the Amplified Fragment Length Polymorphism (AFLP) dendrograms. No significant concordance between AFLP and morphology cluster analyses was observed.

Morphological data are analyzed to generate meaningful interpretation using multivariate analyses such as Principal Component Analysis (PCA), bi-plot analysis and cluster analysis. PCA, for instance, is a technique which identifies plant traits contributing to the most observed variation among genotypes (Afuape *et al*. 2011; Ahmadizadeh & Felenji 2011) which in turn assists to select parent lines for breeding purposes. It measures the importance and contribution of each component to total variance (Lohani *et al*. 2012; Sinha *et al*. 2013). The approach is useful to analyze groups of correlated variables representing one or more common domains. Cluster analysis is yet another statistical procedure for forming groups of similar objects (Khalid, 2011) based on morphological or molecular data. It is a cross cutting tool with

a wide range of application in several research studies. According to Cornish (2007) cluster analysis is a multivariate method aiming at classifying a sample of subjects (or objects) in to different groups/clusters based on a set of measured variables. Moreover, being a multivariate statistical tool, clustering have found extensive use in classifying objects according to their similarity (Harding & Payne, 2012) thus describing the inherent variation in the population of crop genotypes (Afuape *et al*., 2011). The tool is widely used by several researchers for characterization and or crop identity study such as potato (Ahmadizadeh & Felenji, 2011; Arslanoglu *et al*., 2011); sweet potato (Afuape *et al*., 2011; Karuri *et al*., 2010); chili, (Del *et al*., 2007); green vegetable (Denton & Nwangburuka, 2012) and rice (Sinha *et al*., 2013).

Molecular markers, on the other hand, enable the study of variability among cultivars at the DNA level, which has significantly increased the accuracy in assessing the genetic diversity and identifying cultivars (Rocha, Paiva, Carvalho, & Guimarães, 2010). Molecular markers can be used for detection of relationships among different germplasm lines in seed banks, search of promising heterotic groups for hybrid breeding, identification of duplicates in seed banks, and assessment of the level of genetic diversity present in germplasm pool and its flux over time (Schulman, 2007). They are useful not only for the management of *ex situ* germplasm collections to address genetic identification, redundancy, and genetic variation (Ghislain, Andrade, Rodríguez, Hijmans, & Spooner, 2006) but also, are important biotechnology tools in plant breeding programs (Favoretto, Veasey, & Melo, 2011). According to Rosa *et al*. (2010), the analysis of commercial potato varieties with microsatellite markers is efficient in varietal identification and complements traditional morphological characterization. Molecular based characterization, moreover, provide useful information on seed lot purity testing, trueness-to-type confirmation, cultivar identification and confirmation of parentage. Indeed, advances in molecular techniques have enabled the study of genetic variability at the DNA level, which has significantly increased the accuracy in assessing the genetic diversity and identifying cultivars

(Rocha *et al*., 2010). According to Crawford (2000), molecular markers have several putative advantages to analyze genetic diversity, including: freedom from environmental and pleiotropic effects; presence of more independent markers compared with morphological or biochemical data. They are now widely used in various genetic diversity studies of different crops including potato owing to the fact that they are highly reproducible, quick, efficient and reliable in identification of varieties (Ghislain *et al*., 2009; Rosa *et al*., 2010).

2.5.3 Nutritional analysis

Potato is eaten boiled, roasted, baked or fried and is 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 (Kroll 1997; Stark *et al*. 2009). Not all varieties are good for all end uses and, hence, intensive varietal evaluation should be conducted to analyze and identify suitable varieties for a particular use. Despite the great progress in all these years, it is still necessary to assess cultivars for their nutritional content so as to design their best end use. The time required for harvesting of potato, for instance, differs with the varieties, which may extend from 100-180 days. Cultivars have been bred and selected to suit many climatic regions and situations (Kroll, 1997). Thus, plant characteristics and yield vary widely among the varieties.

The most significant factor that may affect quality of potato for processing, for instance, is the variety (Simongo, Gonzales, & Sagalla, 2011). The authors further added that varieties for potato fries must have a tuber dry matter content of 21-24% for high fry recovery, less oil uptake, crispy texture and light yellow or light brown sticks. In general, potato varieties bred for the chipping industry are low in sugars. Potato bred for processing French fries typically have intermediate sugar contents, while those bred for the fresh market usually have high sugar levels (Stark *et al*., 2009).

For most potato varieties, the nutrient content of tubers is about 2% protein and 15–25% starch. The protein composition changes dramatically during stolon-tuber transition resulting in the formation of a much-simplified protein complement consisting of only a few highly abundant proteins such as patatin (Fernie and Willmitzer, 2001). On average (~ 150 g) potato with the skin contains 45% of the daily requirement for Vitamin C; as much or more potassium (620 mg) than either bananas, spinach, or broccoli; and trace amounts of thiamin, riboflavin, folate, magnesium, phosphorous, iron, and zinc all for only 110 calories and no fat (United States Potato Board, 2008). These figures once more vary depending on varietal composition and growing conditions. Potato varieties vary widely in their ability to accumulate starch in the tubers. The choice of variety is probably the most critical decision with respect to matching tuber quality with intended market (Stark *et al*., 2009).

The current study was, therefore, designed to understand the potato farming practices, major constraints, morphological as well as molecular diversity among the cultivars grown in the Eritrea. The study also aims at assessing the nutritional content of the farmers' cultivars for future crop improvement program and ensure optimum nutritional food supply.

CHAPTER THREE

DIAGNOSTIC SURVEY OF POTATO PRODUCTION AND FARMING PRACTICES IN ERITREA

Abstract

A baseline survey was conducted in Zoba Maekel and Zoba Debub, Eritrea, to determine existing potato production practices and identify areas of intervention for optimization of its productivity. Within each Zoba, the Sub-Zoba/village (strata) was purposely selected based on their history and coverage in potato growing, while farms (sites) were randomly selected for the study. Farmer respondents were interviewed (by enumerators) based on a comprehensive set of questions on their potato growing practices. Basic information, on societal structure at house hold and community level as well as potato farming practices, potentials and constraints were collected. Over 93% of the respondents were male with majority falling in the range of 41-55 years old. Almost all the growers (91%) practiced furrow irrigation method using water from open dug and borehole wells. Focus group discussions with selected groups of farmers were also conducted. It was noted from the survey that there was an acute shortage of inputs such as quality tuber seeds (91%), fertilizers (87%) and pesticides (90%) for the respondents. More than 97% of the respondents indicated that lack of inputs discouraged them from increasing their production levels, although transport and marketing access were favourable for the business. Moreover, pest prevalence particularly, late blight infection (97%) and cut worm infestation (87%) were recorded in all the visited villages posing major problem to growers. It is, therefore, recommended that timely provision of major farm inputs and frequent extension services be provided to farmers in order to improve potato production in the country. Special consideration should be given to the establishment of a sustainable quality seed production, marketing and distribution system for the country.

3.1 Introduction

Agriculture is the mainstay for more than 70% of Eritrea's population and one of the most important economic sectors of the country. The main food crops grown include: pearl millet, wheat, barley and sorghum and many forage and horticultural crops. One of the common vegetable crops grown is potato. It is widely grown in the highlands of the country, mainly by small scale farmers with low input low output practice. It is grown both for home consumption as well as for cash. Because of this dual purpose, the crop plays an important role in the rural livelihood system of many countries (Gildemacher, 2012).

Diagnostic surveys to obtain baseline information on potato production practices and/or marketing systems have been conducted in many countries such as Kenya, Ethiopia and Uganda (Gildemacher, 2012); Kenya (Muthoni & Nyamongo, 2009; Muthoni *et al*, 2013); India (Kadian *et al*., 2010); Ecuador (Barrera & Norton, 1999), Indonesia (Dawson, 2012), and Argentina (Caldiz, 2000). However, no such study has been conducted in Eritrea. It has been proven beyond doubt that quantitative and qualitative surveys help to identify the positive and negative management techniques as well as in understanding the potato farming system (Mcpharlin & Taylor, 2005). Furthermore, for improved productivity of potato it is essential that farming systems are understood in enough depth to identify and implement any intervention strategy successfully. According to Gildemacher *et al*. (2009), for instance, for effective targeting of research and development efforts, a more detailed country or region specific analysis of the potato production system and its potential opportunities and possible constraints is required. The survey not only helps to identify relevant areas of intervention, but also helps to identify weaknesses within the system that need to be revised immediately.

The current study was, thus, designed to gather and document potato cultivation system in Eritrea with particular emphasis on land management systems prevailing in the area, household and farm characteristics, cropping pattern, cultural practices, pests and their

control, and yield. It was assumed that the information gathered would assist to identify main areas of intervention needed in order to improve potato productivity and hence the livelihood of growers.

3.2 Materials and Methods

3.2.1 Study site description

The study was conducted in the two major potato producing Zobas (regions) of Eritrea (Zoba Maekel, and Zoba Debub). Zoba Maekel, the smallest of the six Zobas of Eritrea, is located in the center of the country with a total area of 1,040 km^2. The Zoba lies between 15°10' – 15°35'N latitude and 38°41'- 39°30'E longitude, and an altitude of between 1276 (Durfo) to 2625m (Zagir) with an average of 2200 m.a.s.l. Annual rainfall records, from 1997 to 2007 show a maximum of 574 mm in 2001 and a minimum of 297 mm in 2002 (Daniel, Tesfaslasie, & Tesfay, 2009). The mean maximum and minimum annual temperatures of the region are 25.5 ºC and 4.3 ºC, respectively. Agriculture is an important economic activity in this Zoba and for the majority of the population it is a source of livelihood, employment and food security. The potential arable land of the Zoba is estimated at 46,966 ha with a predominant soil type of *Luvisol, Cambisol and Lithosol-Cambisol* (FAO, 1988) (Figure 3.1).

Zoba Debub is located along a portion of the national border with Ethiopia $14^o25'$-$15^o10'$ N latitude and $38^o15'$-$39^o45'$ E longitude. It is the largest region in the country by population. Climate in this area is subtropical with distinct dry winters and rainy summer seasons. The mean annual rainfall ranges between 300 and 700 mm with mean annual temperatures exceeding 22^oC. The region receives rainfall from the southwest Monsoon, between the months of April and September. Some of the rain falls in April/May while the main rain starts in June, with the heaviest precipitation in July and August. The soil type of this region is predominantly *Cambisol, Lithosol-Cambisol and Vertic-Cambisol* (FAO, 1988). Agriculture is an integral economic activity in this Zoba. It is also a major source of livelihood, employment and food.

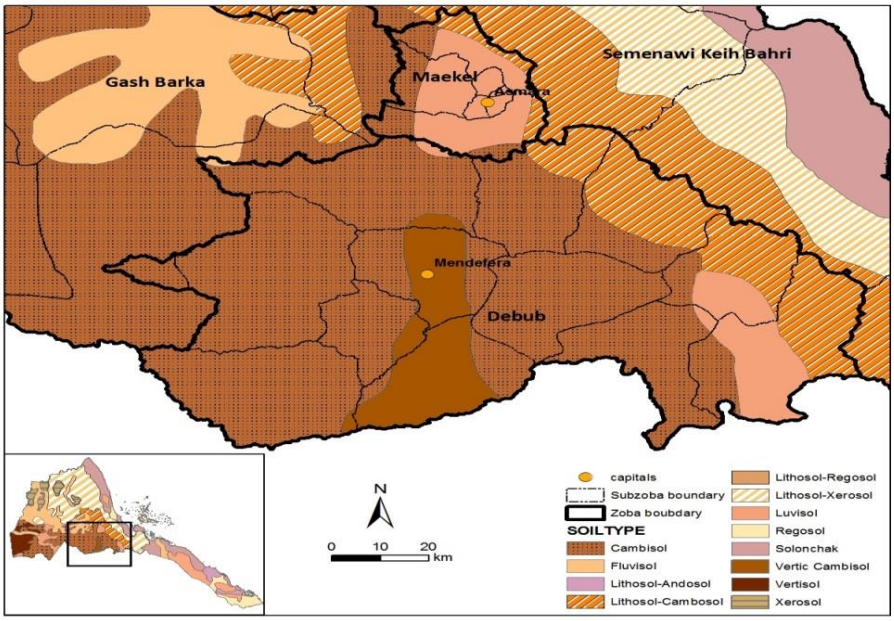


Figure 3.1: Soil map of Zoba Maekel and Zoba Debub, Eritrea (FAO, 1988).

3.2.2 Study and sampling design

The study was carried out by interviewing representative growers using a semi-structured questionnaire prepared for this purpose (Appendix 3.1), discussion with focus group farmers using the participatory rural appraisal (PRA) tools and physical observation.

The semi-structured qualitative and quantitative open ended questionnaire was designed to interview individual growers and field experts to gather baseline information on potato growing systems. The questionnaire contained over sixty individual questions divided into six topics covering general household information, cropping system, seed source and use system, pest prevalence, marketing and list of constraints and potentials. Focus group discussion comprising of the elderly men, women and young growers was also organized. The discussion enabled local people to share their knowledge freely.

For the focus group discussion, representatives from the two Zobas participated separately in the PRA. The participants were selected following the purposive sampling in consultation with the MoA officers considering the experience, gender, age, and educational status. To that effect 20 farmers from Zoba Maekel (15 men and 5 women) and 22 farmers from Zoba Debub (15 men and 7 women) were participated.

Moreover, the sampling design was developed in consultation with officers from each Zoba to identify areas according to their potato cultivation coverage and status. Accordingly, more than 20 villages from each Zoba were identified (Figure 3.2). This was then followed by stratified sampling. It was noted from the informal observation that farmers from the same village use more or less the same farming practices thus was deemed necessary to increase number of villages than number of farmers per village. Sample size was decided following the standard sample size determination equation[1]. Accordingly, 138 farmers from over 40 villages were interviewed.

[1]Sample Size = $\frac{(\text{Z-score})^2 * \text{StdDev} * (1-\text{StdDev})}{(\text{Margin of error})^2}$

Z-score = 95% confidence interval (1.96)
StdDev = 30% for Zoba Debub and 20% for Zoba Maekel
Margin error = ± 5%

3.2.3 Data collection and management

During data collection, quality control process was followed to ensure reliability of the data using statistical software. Throughout the survey, filled questionnaires were reviewed at the end of each day to ensure that all entries were completed appropriately. The principal investigator scrutinized each filled questionnaire to filter errors and non-response/missing data. Any incomplete or questionable entries were sent back to be filled again the next day. To manage the data collected efficiently, data entry forms were developed using EPIDATA data entry and management software (EpiData 3.1).

The data entry software was designed so that it would be as similar as possible to the hard copy questionnaires. Epidata, data entry program allows data merging, cleaning, and validation processes. Data was then exported to the Statistical Product and Service Solutions (SPSS) software package for major statistical analysis. For generating geo-referencing coordinates of visited locations, a global positioning system (GPS-Garmin Oregon 550) was used.

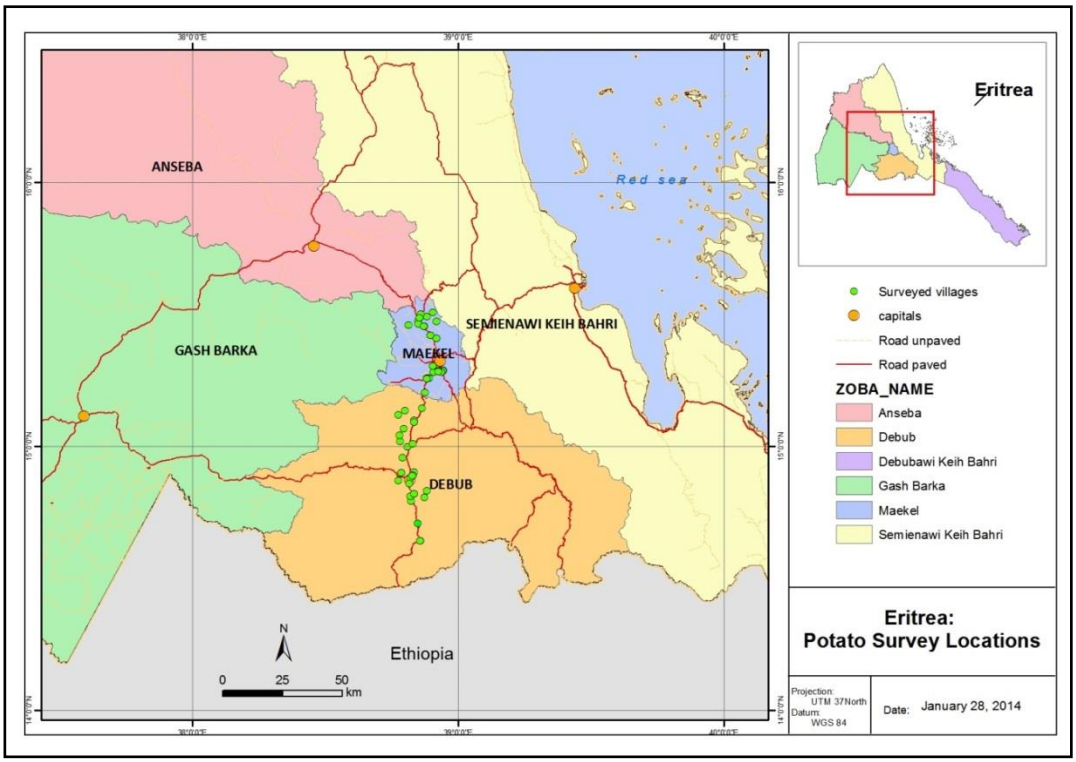


Figure 3.2: Map of the visited villages in Zoba Maekel and Debub (Courtesy: Selam Tesfay, 2014).

3.2.4. Data analysis

Qualitative and quantitative raw data collected from the diagnostic survey were analysed to generate useful information for documentation and to serve as useful reference for scientific community and policy makers. The qualitative data analysis started on the spot at the time of data collection and during discussion with the farmers. Quantitative data from the survey were subjected to a statistical analysis using SPSS for

computational analysis after which results were expressed in the form of means (averages), and percentages. Multiple facets of the data were analysed explaining the variation yield, variety, pests and farming practices across the two Zobas.

3.3 Results and Discussions

3.3.1 Basic household information

This part of the study yielded information on farmers' family size, gender, age, educational level and growers' experience on potato production. The respondent growers were predominantly male (93.5%), ranging between 16 and 85 years of age with an average age of 51 years. Majority of the growers fell in the 41 to 55 years of age (Figure 3.3a). About 52.2% of the growers had no formal education or had elementary school education only. On the other hand the young and middle aged growers interviewed were either high school or college graduates (Figure 3.3b). The average family size at house hold level varied between 5.4 and 7.8. Potato growing experience ranged from 2 to 66 years with majority of them having grown it for more than 20 years (Table 3.1). During the focus group discussion, farmers from the two Zobas mentioned that potato cultivation in the area dated back to the early 20th century.

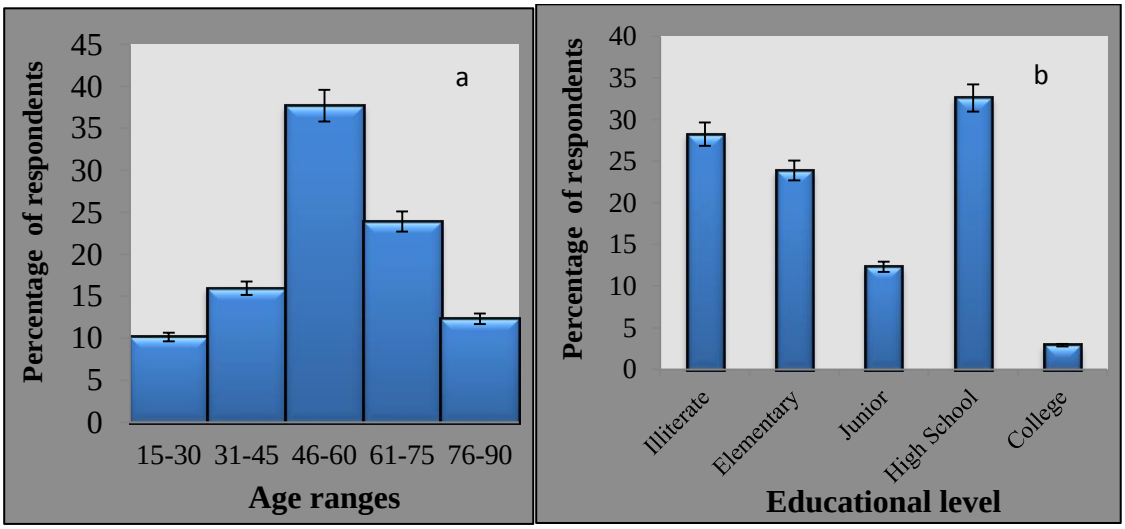


Figure 3.3: Age distribution (a) and educational level (b) of the respondents.

Table 3.1: Basic household and village characteristics

Zoba	Sub-Zoba	Altitude (m.a.s.l)	No Farmers interviewed	Average Family size	Average growing experience
Maekel	Asmara	1995-2454	7	5.4	18
	Galanefhi	1627-2425	17	6.9	23
	Serejeka	1305-2606	30	6.9	36
Debub	Mendefer	1596-2529	37	6.7	27
	Debarwa	930-2567	23	7.4	27
	Emnihayli	1340-2048	13	6.3	21
	AdiQuala	1352 -2148	11	7.8	18
Total	**7**		**138**		

3.3.2 Cropping systems

3.3.2.1 Land management and use

Land tenure and acquisition system of all the surveyed area included *Risty* (individual), *Diesa* (communal), rented and/or shared (contract agreement is made between the grower and owner). In majority of the country's highlands, the *Diesa* system was predominantly practiced. The main characteristics of the system is that the land is basically owned by the community, thus every permanent resident is entitled to share it equally through a periodic redistribution to all community members (Negassi, Bein, Ghebru, & Tengnäs, 2002). In other words farmers only have the right to cultivate the land but not own it. But still farmers could be able to obtain additional farmland through a variety of tenancy arrangements (Tewolde & Ghebreyohanes, 2005). The *Diesa* system is commonly criticized for not encouraging growers to put long-term investment on the land as they know it will be redistributed to others after a certain interval (7 years), although it provides equitable access to all members (FAO 2005; Negassi *et al*. 2002). It is also described as one of the important factors affecting agriculture in general and land management in particular in the country (FAO, 2005). This observation was

reaffirmed by most of the growers during the PRA discussion in the two Zobas. It was noted from the study that majority of the respondents used either *Diesa* and/or rent system. Majority of farmers in Zoba Maekel use rented land while in Zoba Debub use *Diesa* followed by rent systems (Table 3.2). The difference statistical anlaysis using chi-square tool indicate that the land tenure system is significantly different between the two zobas.

Table 3.2: Land management practices in the visited villages

Zoba*	Land tenure systems (%)				Total
	Risty	***Diesa***	**Rented**	**Other [1]**	
Zoba Maekel	27.8	27.8	40.7	3.7	100
Zoba Debub	3.6	47.6	40.5	8.3	100
Total	**13**	**39.9**	**40.6**	**6.5**	**100**

1 Other means shared with the owners; * ($\rho < \alpha$) = (0.017< 0.05) thus the H_0 is rejected

3.3.2.2 Topography and soil type

The topographic nature and soil type of the areas under which potato is cultivated was dominated by being flat with clay soil type (Table 3.3). It's clearly shown from the findings that areas in Zoba Maekel are dominated by sloppy and mountainous topography, especially in sub Zoba Serejeka. This is probably the main reason why only few commercial farms exist around the capital Asmara (FAO, 2005). In contrast, Zoba Debub is characterized by more plateau and flat area, land that is ideal for large scale commercial farming. The presence of relatively more semi-commercial growers in Zoba Debub is partially attributed to this fact. The chi-square analysis (Tabel 3.3) supported to reject the null hypothesis as the nature of topography in the two zobas is significantly different. Whereas, despite some trend of differences in the soil type, there was no statistical difference between the two zobas (Ho is accepted in that regard).

Table 3.3: Topographic and soil characteristics of the visited villages.

Zoba	Sub Zoba	Topography**		Soil type*				
		Flat (0-2%)	Gentle Slope (2-8%)	Clay	Sandy loam	Loam	Silt Clay	Sandy Clay
Maekel	Asmara	85.7%	14.3%	57.1%	28.6%	14.3%	-	-
	Galanefhi	70.6%	29.4%	82.4%	-	11.8%	5.9%	-
	Serejeka	43.3%	56.7%	13.3%	33.3%	26.7%	26.7%	-
Debub	Mendefera	94.6%	5.4%	73.0%	-	5.4%	21.6%	-
	Debarwa	91.3%	8.7%	43.5%	13.0%	8.7%	30.4%	4.3%
	Emnihayli	92.3%	7.7%	61.5%	-	15.4%	23.1%	-
	AdiQuala	90.9%	9.1%	81.8%	-		18.2%	-
	Total	**79.0%**	**21.0%**	**55.1%**	**10.9%**	**12.3%**	**21.0%**	**0.7%**

** $\rho = 0.001 \Rightarrow \rho < \alpha$ ($0.001 < 0.05$) the Ho is rejected; * $\rho = 0.390 \Rightarrow \rho > \alpha$ ($0.390 > 0.05$) thus the Ho is accepted

3.3.2.3 Land preparation

Growers in the study area used different land preparation methods. Farmers in Zoba Maekel prepared their land manually and/or used animal traction. This was in agreement with an earlier study by (FAO, 2005) where it was mentioned that land preparation in Zoba Maekel is largely carried out with traditional oxen-drawn plough. Growers from Zoba Debub, on the other hand, used manual labour and animals (16.7%); manual and tractor (9.7%) with the majority using combination of all methods (73%) for preparation. It was slightly different in case of farmers from Zoba Maekel where only 44.4% used a combination of all methods (Figure 3.4).

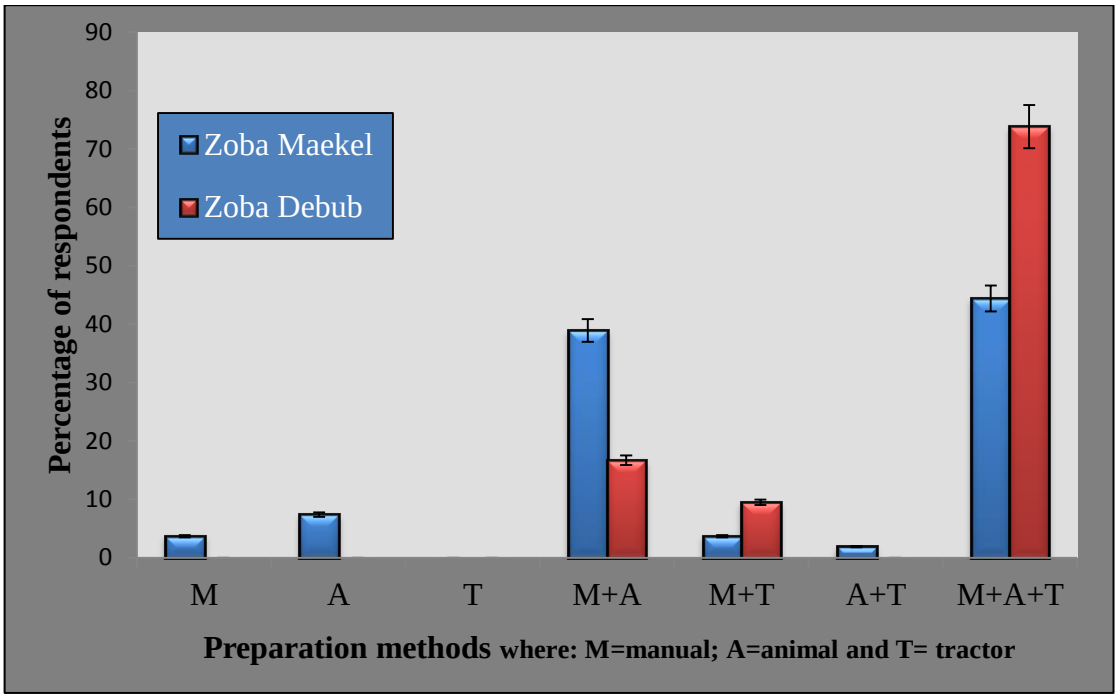


Figure 3.4: Land preparation methods for potato cultivation in the two Zobas.

The average farm size of the growers during the on-season (rain fed) ranged from 0.2 to 13.5 ha (including rented), and was 0.2 to 20 ha during the off-season (irrigation system). Accordingly, areas cultivated with potato differed substantially between individual farms. It's worth mentioning, that more than 60% of the farmers owned a land size of less than 2 ha. Earlier, it was reported by Tewolde and Ghebreyohanes (2005) that average land holding is at a maximum of 1 ha in Eritrea.

The results of this study indicated that about 62% of the growers allocated part of their land for potato production during the rainy season and about 93% during the off-season. This result clearly indicates that potato is a priority crop both during the on and off-season of the year for most of the growers. According to Janssens *et al*. (2004) European potato growers (farmers) use 5 to 15% of their arable land for potato crops and in exceptional circumstances reaching up to 30 to 47%. The current result further showed that the average land allocated for potato ranged from 0.05 to 5 ha and 0.1 to 10

ha during on season and off-seasons, respectively. It was, however, noted that more than 65% and 67% of the growers during the on season and off-seasons, respectively allocated less than 1 ha of their land for potato. This confirms the previous findings by several authors that potato production in Eritrea was practiced by small scale farmers. More or less the same farming pattern was reported in Kenya (Muthoni *et al*., 2013). When the distribution and land allocation for potato in the two Zobas was compared, growers in Zoba Debub owned larger area both for rainfed and irrigation. This could be ascribed to the fact that the topography is suitable in Zoba Debub and a majority of the growers are semi-commercial thus have better access to resources and are able to rent larger area.

3.3.2.2 Planting

The on-season (rainfed) farming is practiced during the summer season (June-September) while the off-season is mainly during autumn (September- December) and spring (March-June) periods of the year (Figure 3.5). The range and period of the on and off-season might vary from one location to another. To this effect, growers in Zoba Maekel start their on-season planting time early towards the end of June. Whereas growers in Zoba Debub start planting late between mid of July to August (results obtained from focus group discussion). This variation could be associated mainly to the varieties used and farming practices. In Zoba Maekel, majority of the farmers planted local cultivars (especially during on-season) which took longer time to mature. As a result, it should be planted early in order to make use of the rainfall effectively. Another interesting point raised by the growers during the group discussion was that farmers opted to plant local cultivars instead of improved/imported varieties because local cultivars had shorter dormancy. Thus, the local cultivars become ready for planting before the imported ones, although the former require more water and time to reach maturity. They were all aware that the crop should not be subjected to water shortage, especially after flowering (critical period). Thus, the growers preferred to plant the farmers' cultivars during the long rainy season (summer) period. The same approach

was reported by Kadian *et al*. (2010) on Indian growers. In Eritrea, the rainfall during the short rains, known as *Azmera* (March-May), summer rains known as *Kremti* and winter rains account for 17%, 76% and 7% of the total annual rainfall, respectively (Ahmad *et al*., 2003; Habte, 2005). According to the authors, the *Kremti* rains in June account for 10%, July 43%, August 41% and September 6% of the total seasonal rains.

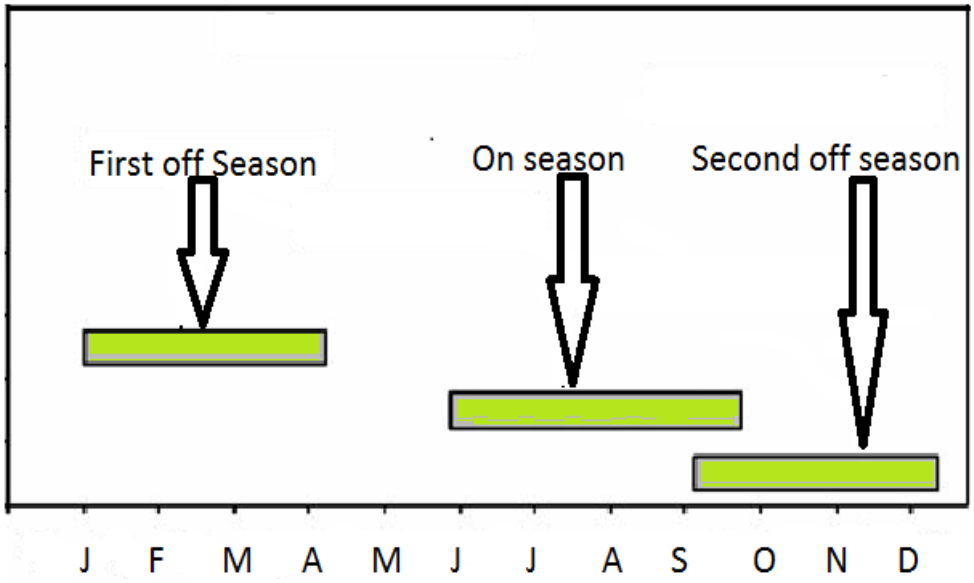


Figure 3.5: Cropping pattern of potato in on and off-seasons of the year.

About 43.5% of the respondents applied some kind of pre-sowing treatments to disinfect their planting seeds, majority of whom dressed it with *Sevin* in the store before sowing. Similar cases were reported for Ecuadorian farmers where about half of the producers disinfected their seeds each year before planting (Barrera & Norton, 1999). This is meant mainly to protect seeds from insect infestation in the store particularly potato tuber moth (PTM). Others applied locally available ash and made frequent sorting to reduce any damage from insects. Most of the farmers stated that they used no specialized quality grading system prior to storage. It was also observed from the survey that most of them did not have proper storage facility; they instead used a separate living room of different size that could provide optimum aeration and humidity usually

cooled by ambient air. This system is widely practiced across all Eastern African countries leading to low yields (CIP 2011).

Almost all (90%) the surveyed growers stated that they use whole seed planting method with few planting both whole and cut seeds. The same trend was reported by potato growers in Northern India where majority of farmers plant whole tubers, although some farmers who did not have enough small size tubers cut bigger tubers to plant them as seeds (Kadian *et al*., 2010). During the current survey, the growers indicated cutting was not common because they thought that the seed tuber would get rotten immediately if cut into pieces. As a result they planted it whole tuber even if when it was big in size and seeds are insufficient. Others did not have any idea on the practice of seed cutting.

Seeding rate of potato ranged from 0.4 to 3 tons/ha. A wide difference between the two Zobas was evident in such a way that majority of the growers in Zoba Maekel used about 1.2 tons/ha while those in Zoba Debub used almost 2 tons/ha. Seeding rate of 1.5 tons/ha was reported for Indonesian farmers by (Dawson, 2012). The lower seeding rate in Zoba Maekel could be ascribed to the fact that most farmers in this Zoba used the local cultivars such as *Tsaeda Embaba*, *Keyh Embaba* and *Shashemanie*. These cultivars are known for having small sized tubers as compared to the imported ones thus making the total weight of seeds relatively lower. According to Dawson (2012) small seed tubers are favoured in some parts of Indonesia due to their lower cost as seed potatoes are usually sold by weight.

3.3.2.3 Cultural practices

Crop rotation

It was noted from the survey that >98% of the respondents practiced crop rotation with different crop types mainly cereals, legumes and other vegetable crops (Figure 3.6). The

most remarkable point is that, all the growers were fully aware of crop rotation and its ability to improve soil fertility and suppress soil borne diseases and insect buildup. According to Janssens *et al*. (2004), crop rotation is a crucial element of the soil fertility management strategy. Unfortunately, for some of the growers, especially in Zoba Maekel sub Zoba Serejeka, crop rotation was not commonly practiced, owing to the relatively low land availability. Janssens *et al*. (2004) reported that even for growers in developed countries like Europe, the crop rotation patterns are not typical for specific growers and there is no obvious relationship between soil type and crop rotation, indicating that farmers adapt the crop rotation pattern to specific needs and less to the environment.

Intercropping

Most of the growers (97.1%) responded that they grew potato in pure stands (Figure 3.6) with very few remaining included maize, especially along the border of the seed bed, as a means of windbreak. Potato sole cropping was also most common in Ethiopia with occasional intercropping with maize and or beans (Emana & Nigussie, 2011). Potato intercropping is, however, a common farming practice in some other parts of the world. In Ecuador, for instance, most farmers plant a combination of other crops such as wheat, barley, corn, faba beans, peas, and forage in addition to potatoes (Barrera & Norton, 1999). It is grown in multiple cropping systems in rotation with other vegetables or cereal crops in many parts of Asia and Pacific (Pandey, 2008).

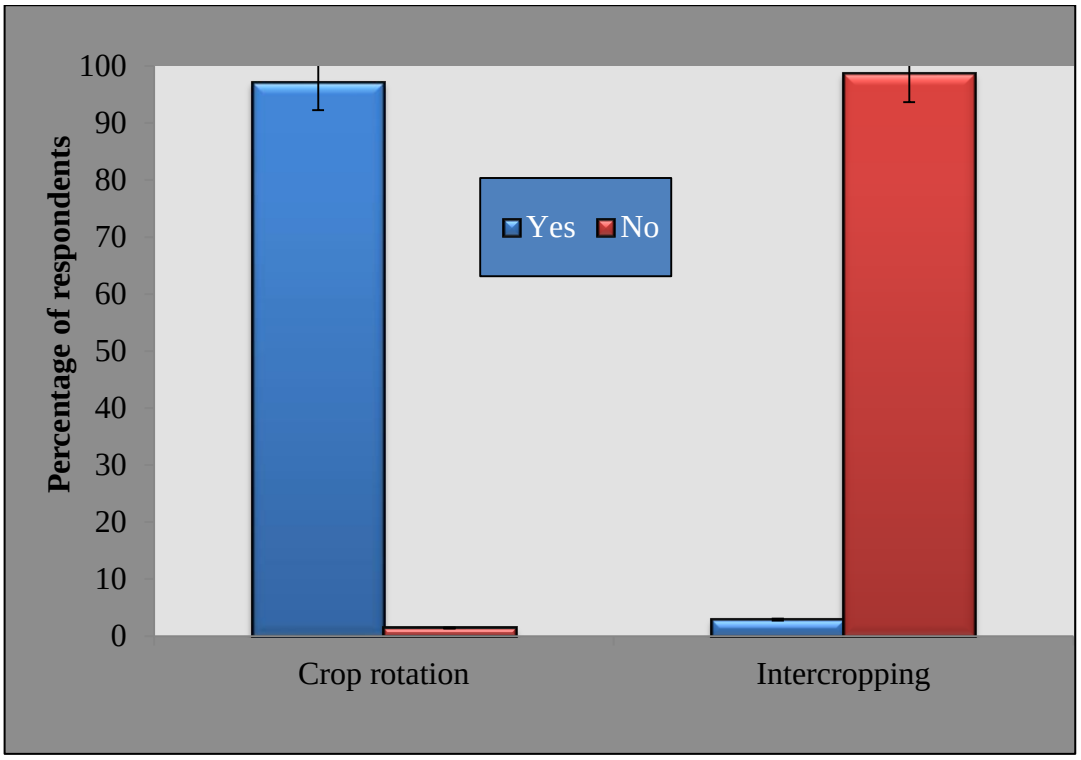


Figure 3.6: Crop rotation and intercropping practices by the growers.

Irrigation system

Over 91% of the respondents use the furrow irrigation system (Figure 3.7, left). They are accustomed to the furrow irrigation system because it did not require any special skill and resources. This agrees with the previous report by Tewolde and Ghebreyohanes (2005) and Negassi *et al*. (2002). This method is, however, known for its excessive water use and water loss as compared to the other methods. All the growers owned (or hired) water-pump generators to collect and distribute irrigation water from wells into the furrows. More than 84% of the respondents collected water from wells and only a few from dams and streams (Table 3.4). This agrees with previous report by Negassi *et al*. (2002). The authors reported that since there were no perennial rivers, streams or lakes, for most growers in Eritrea, wells and dams were the main sources for irrigation water. Although, there are two types of wells (open dug and borehole wells) almost all in Eritrea are dominated by the former type (Figure 3.7,

right). This is mainly because all the growers find it easier and cheaper to construct and maintain open dug well (Negassi *et al*., 2002). The chisquare analysis further revealed that there was a significant ($\rho<0.001$) difference between the two zobas with regards to their water sources and irrigation systmes coverage (Table 3.4). The findings support to reject the null hypothesis.

Table 3.4: Water sources and irrigation methods of the visited villages.

Zoba	Sub Zoba	Water source**				Irrigation system**		
		Well	Stream	Dam	Other[1]	Drip	Furrow	Other[2]
Maekel	Asmara	100%	-	-	-	-	100%	-
	Galanefhi	100%	-		-	-	100%	-
	Serejeka	40%	16.7%	10%	33.3%	-	66.7%	33.3%
Debub	Mendefera	97.3%	-	2.7%	-	-	100%	-
	Debarwa	100%	-	-	-	-	100%	-
	Emnihayli	84.6%	7.7%	-	7.7%	7.7%	84.6%	7.7%
	AdiQuala	100%	-	-	-	-	100%	-
	Percentage	**84.8%**	**4.3%**	**2.9%**	**8%**	**0.7%**	**91.3%**	**8%**

[1]Rain fall [2] Overhead rainfall irrigation

** P=0.001=> $\rho<\alpha$ (0.001<0.05) thus the Ho is rejected.

Figure 3.7: Furrow irrigation (left) and well main source of irrigation water (right).

Fertilization

All the growers interviewed agreed that they should apply either organic and/or inorganic fertilizers to boost-up productivity. According to Wolfe & Kipps (2004), compared to most other important vegetable crops, the potato crop removes more total nutrients and a high ratio of potash from the soil. Farmers are generally aware of the importance of fertilizers and almost all the growers applied fertilizers to their fields in one way or another. The most commonly used fertilizer types were Di-ammonium Phosphate (DAP), Urea and farmyard manure (FYM). The study indicated that most growers used a combination of fertilizers, although the degree and level varied from one grower to another and from one Zoba to another. In Kenya, farmers use considerable amounts of inorganic fertilizer (DAP) and FYM, while in Ethiopia, only inorganic fertilizers are widely used in potato production (Gildemacher, 2012). In general, many of the growers in the current study expressed their dissatisfaction that they had limited access to fertilizers. Consequently, over 80% of the respondents complained that there was insufficient fertilizer supply. Thus, they were forced to purchase from the market at a higher price. Although the amount and its availability were highly limited, sometimes the MoA provided them fertilizers at a reasonable price. Others used their own FYM yet very few borrowed from their friends (Figure 3.8). Motives to use FYM included economic considerations (availability on farm) as well as agronomic reasons since FYM was generally considered a fertility input (Janssens *et al*., 2004). In a similar manner about 52% of the growers mentioned that they used more fertilizer during the off-season than in the on-season period. This could be attributed to the indigenous knowledge of the growers where ample water application is essential right after fertilizing to prevent crop burn. In general, application practices vary depending on rainfall, soil type, crop rotation, and type of farming system (Wolfe & Kipps, 2004).

Pesticide application

As a routine practice of potato cultivation, growers in Eritrea used different types of insecticides and fungicides. The types used vary depending on factors such as price, availability, accessibility, knowledge, season and location of the site. The types of insecticides used include but are not limited to: *Malathion, Focus, Dursban, Roger, Cypermethrine* and *Ectodip.* While *Ridomil, Mancozeb, Zulfo, Anadoul,* and *Dithane* are used as fungicides. Nevertheless, all the growers admitted that they used at least one type of pesticide. Table 3.5 shows that majority of the growers (97.1%) used *Malathion* followed by *Focus* (58.7%) to control insect infestation whereas *Zulfo* followed by *Mancozeb* are among the widely used fungicides. More than half of the respondents replied that they applied more fungicides during the rainy season because it was associated with high disease prevalence, especially fungal diseases.

Table 3.5: Types of pesticides used by potato growers in Eritrea

Pesticides used					
Insecticide	**Frequency**	**Percent**	**Fungicide**	**Frequency**	**Percent**
Malathion	134	97.1	Zulfo	125	90.6
Focus	81	58.7	Mancozeb	106	76.8
Roger	29	21.0	Ridomil	49	35.5
Dursban	25	18.1	Dithane	10	7.2
Cypermthrine	10	7.2	Anadoul	6	4.3

There was an acute shortage of pesticides for most of the growers. Figure 3.8 shows that majority of the growers obtained their pesticide inputs from the market with limited amount available from the MoA. To make matters worse, the pesticides from the market were not only expensive but were also not properly labeled and expiry dates were not clear. This situation exposes the applicants to serious health hazards, causes environmental pollution and ultimately increases cost of production.

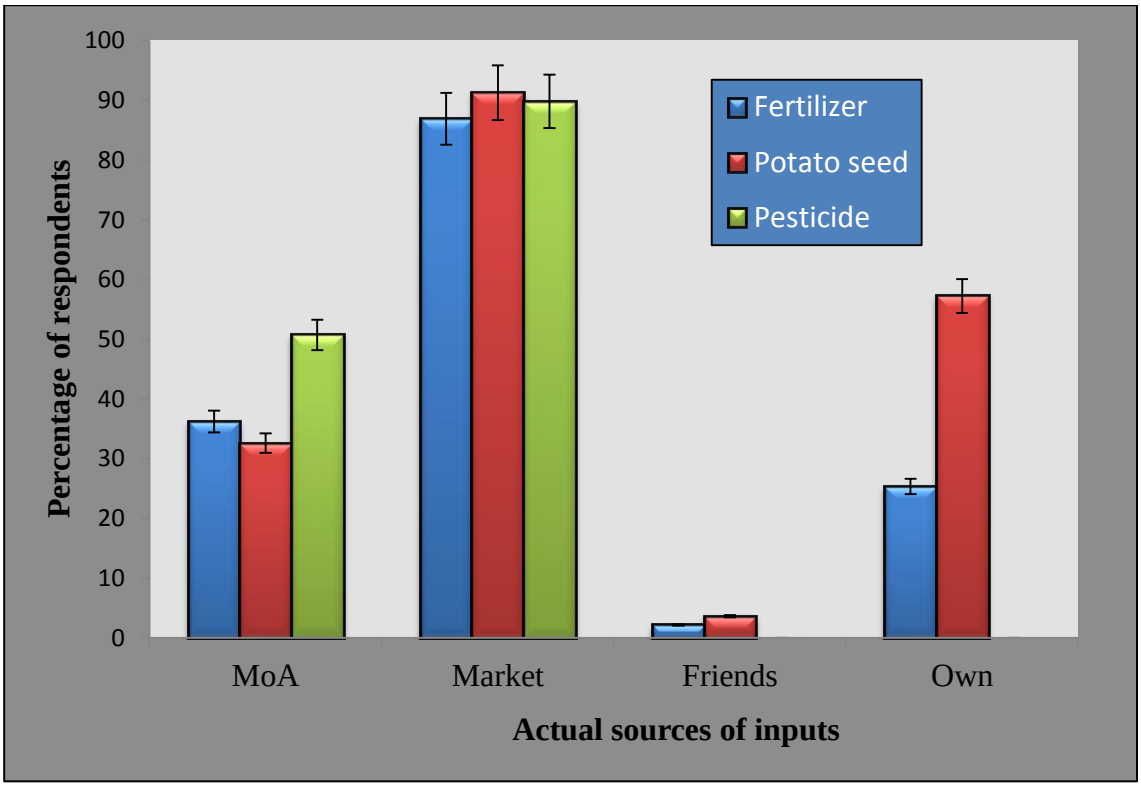


Figure 3.8: Actual sources of cultivation inputs

3.3.3 Seed availability

Good quality seed is a very important factor to optimize productivity. Availability of quality and certified potato seeds was the major constraint across all the visited locations. There is no standard seed supply and distribution system in the country. It was also reported by CIP (2011); Emana and Nigussie (2011) and Gildemacher (2012) that in the three neighboring countries (Kenya, Uganda and Ethiopia) the seed potato system is characterized by a limited availability and use of commercially traded high quality seed potato. The major constraint of potato production in the Asia and Pacific region is also the inadequate supply of reasonably priced, farmer-preferred, quality seeds (Pandey, 2008).

3.3.3.1 Seed sources

The Ministry of Agriculture had imported certified seeds from abroad several times in collaboration with different partners, but it has not been able to meet the high demand by the growers. During the focus group discussion, the farmers put forward their concerns that the amount of imported seeds by the MoA was not only insufficient, but also unfairly distributed. The Ministry, however, indicated that it has set of criteria for distribution of seeds, which include size of land, water availability, resource availability, experience and willingness to grow potato. Nonetheless, this acute shortage of standard seed has led to illegal importation of seeds from neighboring countries by various traders either licensed or otherwise. It is not surprising, hence, to observe that majority of the respondents obtained their seeds from unknown market sources. A similar phenomenon was reported by Muthoni *et al*. (2013) where farmers in Kenya are forced to use seeds from informal sources such as farm-saved (own seed), local markets or neighbours, because of shortage of clean planting materials. Moreover, Emana and Nigussie (2011) reported that the major seed potato system in Ethiopia in all potato growing areas of the country was informal. Figure 3.8 shows that about 91.3% of the respondents purchased seed from the market in addition to their own reserved seed from previous harvest and/or obtain from the MoA. Barrera and Norton, (1999) reported that a wide variety of potato seeds were planted and farmers replanted the same seeds repeatedly for about five years, although most (72%) bought some new seed each year in Ecuador. Similarly, farmers in Ethiopia, Kenya and Uganda renewed their seeds after 3, 6 and 7 seasons, respectively (Gildemacher, 2012).

Potato growers, in the region, mostly chose to use seed from their own harvest with higher disease levels, or purchase seed from a neighbor or the local market (CIP, 2011). Farmers select small sized potato, from the ware potato, and use them as seed in Ethiopia (Emana & Nigussie, 2011). On the other hand, termination of the government subsidized certified seed distribution in parts of India, resulted in abrupt decrease of area under cultivation (Kadian *et al*., 2010). Although the illegal importation in Eritrea,

has contributed immensely to ease the problem it, however, has created an unnecessary duplication of varieties and has become a means of new disease entry to the country. Unless an immediate action is taken to control the free movement of potato seeds, the situation is likely to get worse. More importantly, since potato is largely propagated by tubers, there is a great risk of introducing alien pathogens or pests (Pandey, 2008).

The results further revealed that about 63% of the growers in Zoba Maekel reserved their own seeds for the next generation as compared to only 53.6% from Zoba Debub. The finding confirmed that majority of growers in Zoba Maekel used their own seeds since the desired cultivars were no longer available in the market. The farmers indicated during the PRA discussion that sharing of potato seed with friends was not a common practice among potato growers in the two Zobas. But if it happens, they did it in kind not in cash. In contrast, potato farmers in Ethiopia commonly sell seeds to each other (Emana & Nigussie, 2011). The most important sources of seed potato in Kenya were neighbours, while in Uganda and Ethiopia the village market was the dominant source (Gildemacher, 2012). Although the farmers' cultivars were preferred by the growers owing to their adaptability and consumer preference, they were used frequently without being renewed and their potential became degraded with time. Unless a renewal and preservation scheme was introduced, therefore, their availability will only be short lived.

3.3.3.2 Cultivars grown

As part of the current survey, identification and preference of potato cultivars by the growers and their estimated time of introduction to the area was assessed. Some of the widely grown potato cultivars in the country include: *Carneshim, Yeha, Tsaeda Embaba, Keyh Embaba, Shashemanie, Ajiba, Cosmos, Spunta, Zafira, Picaso, Desirée, Kondore, and Grandinaine.* Some of these cultivars may not be available currently or are localized to a specific area and with a handful of farmers. Majority of the

respondents mentioned that they were very much familiar with *Tsaeda Embaba* followed by *Ajiba* and *Spunta* (Figure 3.9). For unknown reasons almost all the respondents preferred a variety with a white flower colour such as *Tsaeda Embaba* and *Ajiba*. They believed that white flowered cultivars is resistant to various stresses and is also high yielding compared to other cultivars. The cultivars with the same name in Ethiopia were also considered as disease resistant and preferred by the farmers (Emana & Nigussie, 2011). On the other hand very few knew about *Grandinaine, Kondore* and *Desirée* varieties. The *Grandinaine* variety, for instance, was only grown in one village, *Adimongonti*, Zoba Debub. Similarly the *Kondore* and *Desirée* were varieties imported from abroad but were only distributed to a few localities because of their limited amount.

The survey further attempted to understand how long each of the cultivars has been grown and which ones were preferred from the growers' point of view. Accordingly, it was mentioned by the respondents that most of the existing varieties were recently introduced during the last 10 years. The imported varieties, according to the growers, have some advantages like early maturity; high yield (in their first generation) and are marketable and thus, highly preferred by growers, especially by the semi-commercial ones. In addition, the erratic and usually short rainy season only indulges for early maturing varieties to reach full maturity. This trend of seeking for imported and new varieties by the growers (mainly the semi-commercial ones) has exacerbating the rapid disappearance of the old farmers' cultivars from the field. Over time some potato cultivars have been rejected and replaced by others in Kenya; low yield and susceptibility to diseases were cited as the major weaknesses (Muthoni *et al*., 2013). Nonetheless, most of the growers prioritized the following parameters as important when selecting a variety: yield, maturity time, marketability, resistance to stress and taste.

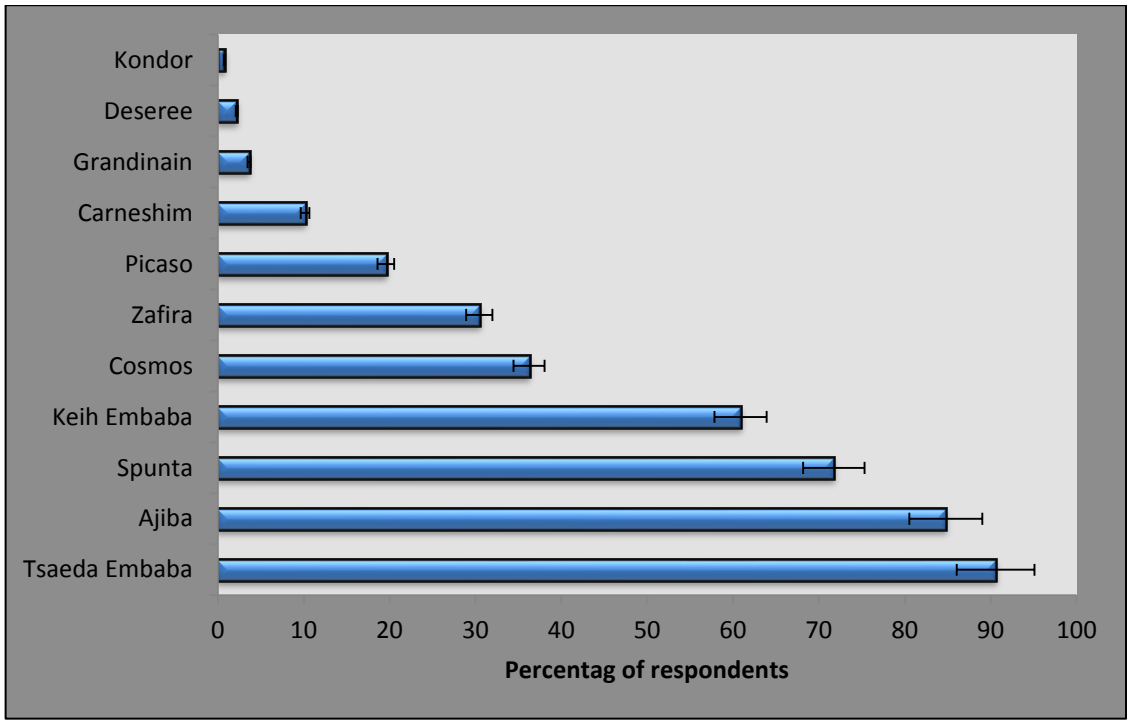


Figure 3.9: Widely grown cultivars by respondents based on their availability, yield, maturity and marketability.

Growers depended on tuber shape, tuber colour, flower colour and leaf shape for variety identification. Over 76% of the growers preferred the round shaped and white coloured potato tubers which include *Tsaeda embaba*, *Ajiba* and *Zafira*. Yet about 16 % mentioned that they preferred the oval shaped and white coloured tubers which include S*punta* and *Cosmos* to mention some (Table 3.6). The yellow coloured cultivar, which was preferred mainly by Zoba Maekel growers, is the old cultivar *Carneshim*, a variety that was common only in Zoba Maekel.

Some of the reasons for cultivar preferences were marketability, yield, resistance, taste and earliness, in that order. The choice and order was more or less the same across the two Zobas with a slight difference. In a previous study in Kenya, variety preference by farmers was attributed to high yield potential, late blight resistance, taste, maturity period, market demand, bacterial wilt resistance, tuber size, and drought tolerance

(Kaguongo *et al*., 2008). Yet others based their selection on tuber quality characteristics as per the consumers interest. The current study revealed that consumers preferred a round shaped and white coloured tubers followed by oval shaped and white coloured. According to Janssens *et al*. (2004), most consumers made their potato variety preference based on variety, taste, cooking type, outside colour and appearance, while convenience and inside colour are less important. It was noted from the analysis that the preference of cultivars by the gorwers significantly differ between the two zobas.

Table 3.6: Preferred potato tuber shape and colour by growers in the two Zobas.

	Preferred tuber shape and colour					Total
Zoba**	Round White	Round Yellow	Oval White	Oval Yellow	Oval red	
Maekel	57.4%	11.1%	22.2%	3.7%	5.6%	100%
Debub	88.1%	0.0%	11.9%	0.0%	0.0%	100%
Total	**76.1%**	**4.3%**	**15.9%**	**1.4%**	**2.2%**	**100%**

** $\rho=0.001 \Rightarrow \rho<\alpha$ (0.001<0.05) thus the Ho is rejected.

3.3.4 Insect Pest and disease prevalence and control

Pests are the main yield reducing factors in all cultivated crops. Likewise potato is a host crop to a number of insect pests and pathogens impairing productivty or usefulness of the crop. In the current study, all the interviewed farmers unanimously reported that insects and diseases were a major constraint to potato production. A number of existing and newly introduced insect pests and pathogens infested and infected, respectively, their potato crop frequently. According to Hooker (1981), potato is a high-value crop with complex production, storage and utilization problems that requires appropirate prevention practices. All the growers mentioned that diseases were common during the rainy season while insect pests were common and troublesome during the off-season especially if crops were subjected to low water supply. It was reported by Barrera and Norton (1999) that late blight is a more severe problem during rainy periods and weevil infestation during dry periods.

3.3.4.1 Insect pests

In the visited farms, the most common insect pests included: cut worms, aphids, potato tuber moth (PTM), whiteflies, stinging bugs in order of their economic severity. The insects attack potato in both the field and stores. Most of the respondents had a problem with cut worms and aphids followed by PTM (Table 3.7). Although the distribution and prevalence of the insect pests were relatively different across the two Zobas, but were not statistically different. Thus the finding suuports to acceote the null hypothesis in this regard. The distribution and frequency of pests might vary depending on factors such as season of the year, location and cultivation method. As a consequence, in Zoba Maekel, PTM followed by cut worm and aphids were the most prevalent insect pests with the least significant being stinging bug preceeded by whiteflies (Table 3.7). The situation was quite different in Zoba Debub where aphids followed by cut worms and white flies were prevalent. The presence of PTM was relatively lower in Zoba Debub. This could be ascribed to the fact that first PTM were seed borne insects and Zoba Debub growers purchased their planting clean seeds from the market with low or no own seed use, a practice that wasn't very common in Zoba Maekel. Secondly, the insect could easily be controlled via ample irrigation water application to prevent soil cracking that allows moths to reach the tubers (CIP, 1996): thus growers in Zoba Debub were better endowed with the water resource. Another essential point of discussion is the relatively higher level of whiteflies incidence in Zoba Debub. CIP (1996) reported that plant infestation by whiteflies was often the consequence of biological imbalance resulting from the intensive use of insecticides. It was noted from the current survey that farmers in Zoba Debub used relatively more pesticides than those in Zoba Maekel, since majority of them are semi-commercial.

Table 3.7: Major insect pest infestation reported by the growers.

Zoba*	Growers response to the occurrence of insect infestation (%)				
	Cut worm	**PTM**	**Aphid**	**White fly**	**Stinging bug**
Maekel	83.3	85.2	83	27	3.7
Debub	89.3	79.8	90.5	85.7	4.7
Total	**87**	**81.8**	**87**	**63**	**4.3**

*ρ=0.215 => ρ>α (0.215>0.05) thus the Ho is accepeted.

3.3.4.2 Diseases

Potato hosts a number of disease causing pathogens, among which late blight, early blight, common rust, *Fusarium* wilt, powdery mildew and viruses were recorded. In almost all the visited farms, late blight was noted to be a major problem followed by common rust and wilt. Several authors have reported that late blight (*Phytophthora infestans*) is probably the single most important disease of potato, world wide, although control measures do exist (CIP, 1996; Winch, 2006). It was also reported that the disease posed major problem for potato growers in Ethiopia (Emana & Nigussie, 2011); Uganda, Ethiopia and Kenya (Gildemacher *et al*., 2009); Indonesia (Dawson, 2012); Asia and Pacific (Pandey, 2008). According to Tamm *et al*. (2004) between 50 and 100% of the interviewed potato farmers in most European countries responded that late blight epidemics caused significant yield losses. Under suitable environmental conditions the disease can spread rapidly and it can cause complete crop loss (Janssens *et al*., 2004). The authors further added that the extent of the economic damage varies depending on factors such as production systems, climate, choice of variety, soil management and use of crop protection schemes. Unless proper and timely protection systems are used, the disease will remain highly destructive disease of potato. The disease is more troublesome during the rainy season, and is less important in dry, hot irrigated areas. It is also favored by temperatures between 10 and 25°C, accompanied by heavy dew or rain (CIP, 1996). It is, thus, preferable to see the spatial distribution of

the disease prevalence across the regions so as to formulate appropirate and relevant control measures.

The results indicated that late blight ranked first in importance in Zoba Maekel and Debub followed by *Fusarium* wilt in Zoba Maekel and by common rust in Zoba Debub. In general, the fungal problem was more serious in Zoba Debub than in Zoba Maekel. This might be related to the amount of rainfall received in the two regions whereby Zoba Debub receives higher rainfall than Zoba Maekel. On the other hand, *Fusarium* wilt incidence is higher in Zoba Maekel (70%) compared to less than 20% in Zoba Debub (Figure 3.10). This could be attributed to its mode of trasmission, as it is a seed borne disease. According to CIP (1996), some of the *Fusarium* strains become systemic and are seed transmitted. Most of the growers in Zoba Maekel used their own seed quite frequently, which explains the high prevalence of the disease. With regard to early blight, although not considered to be serious by most farmers, was higher in Zoba Debub (41.7%) than in Zoba Maekel (30.2%). It was reported by CIP (1996) that early maturing varieties were more susceptible to early blight, than the late maturing ones. In view of this, it could be inferred that the early maturing varieties more commonly grown in Zoba Debub than in Zoba Maekel, may be the cause of the higher incidence of early blight in the former than in the later region.

On the other hand, the viral infection was higher in Zoba Maekel compared to Zoba Debub (Figure 3.10). It was also reported by Biniam & Tadesse (2008) that local (farmers') cultivars (*Tsaeda Embaba and Keyh Embaba*) were more infected with viruses compared to the imported ones. This could be attributed to the seed source and use system practiced in the two Zobas. Most of the farmers in Zoba Maekel used their own saved seed for several generations. This continuous recycling of old seeds without replenishment aggravates the situation. Hence, it is not surprising to find high levels of viral diseases in the local varieties (Biniam & Tadesse, 2008) where the seeds become safe havens for the viruses. Seed degeneration is primarily caused by several tuber-

borne pathogens, the most important being viruses and bacterial wilt (Dawson 2012; CIP 2011). Thus, using only seed-potatoes from healthy mother plants can decrease the pressure of the disease considerably (Wang 2008).

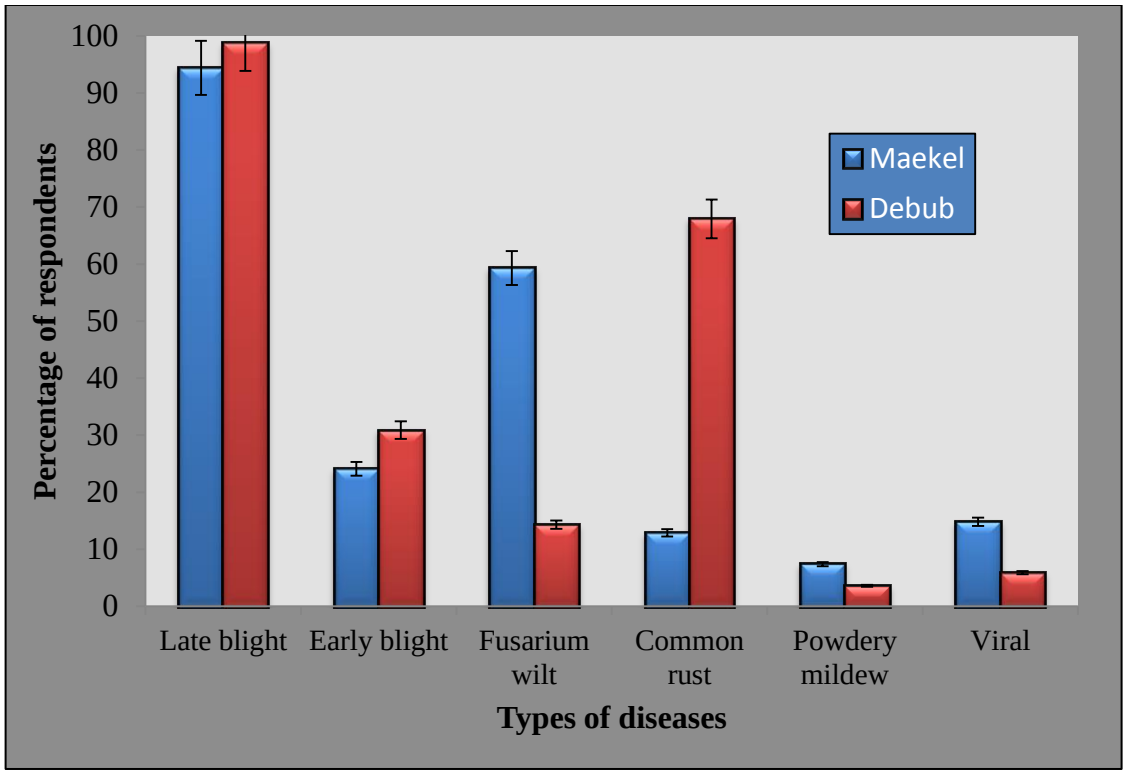


Figure 3.10: Major diseases affecting potato cultivation in the two zobas

3.3.4.3 Insect pest and disease control methods

The growers attempted and used different methods for controling insects. Among the different methods used was, chemical application (>95%) followed by cultural practices (63%) were dominant, with limited numbers using physical methods. Biological control method was obviously impractical and no one reported using it. Majority of the farmers depended on frequent application of chemicals, thereby adversly contributing to environmental pollution in the region. To make matters worse, the type and dosage of chemicals used were neither monitored nor suppervised regularly, and thus, growers

applied whatever was easier and/or more accessible to them. The timing of sprays is usually based on local experience or actual outbreak of the epidemic. Only few farmers decided when to spray based on relevant information and/or advisory services. These results were in agreement with those of Barrera and Norton (1999) who reported that several farmers from Ecuador experimented with different mixtures of chemicals until they found a perfect combination. The cultural practice proved to reduce spread of the disease through crop rotation, rouging out and disease free seed selection. This should be encouraged more for effcient and sustainable crop protection strategy. The chisquare analysis indicated that there was no statistical difference (Table 3.8) between the growers from the two zobas on the methods used to control diseases.

Table 3.8: Pest and diseases control methods

Zoba*	Chemical	Cultural	Physical	Biological
Maekel	85%	57%	14.8%	-
Debub	100%	66.6%	7%	-
Percentage	95.6%	63%	10%	-

* ρ=0..302 => $\rho > \alpha$ (0.302> 0.05) thus the Ho is accepted

3.3.5 Maturity and yield

Maturity time of the potato cultivars grown varied from three to four months. Most of the recently imported varieties were early maturing with a maximum of 90 days after planting (DaP). The farmers' cultivars were late maturing and took up to 120 days to mature. As previously mentioned, farmers in Zoba Maekel grew mainly the old potato cultivars, which are late maturing. Findings of the current survey, hence, confirm the above statement where 24.1% and 4.8% of the respondents from Zoba Maekel and Zoba Debub, respectively grew late maturing along with early maturing ones (Table 3.9). The semi commercial and market oriented growers in Zoba Debub used mainly the imported early maturing varieties to get early return for their investment. The same occurrence was reported by Muthoni *et al*. (2013) where early maturity is considered as important

for food security for enabling growers generate income early to meet their financial obligations. It is also an important trait in potato growing areas with a high demand for land as early harvesting allows more crop cycles within a year. Maturity time, lower yield and short rainy season are the main reasons for the rapid disappearance of the old cultivars from the farm. The chisquare analysis revealed that there is a significant variation (ρ=0.01) between the types of cultivars used by growers in the two zobas.

Table 3.9: Maturity time of the varieties grown in the two Zobas.

Zoba**	Maturity time of varieties grown	
	3 Months	**4 Months**
Maekel	75.9%	24.1%
Debub	95.2%	4.8%
Total	87.7%	12.3%

** ρ= 0.01 => $\rho<\alpha$ (0.01<0.05) thus the Ho is rejected.

According to the growers the yield of potato in the surveyed areas widely varies depending on the farming methods, season and sites. Potato yield is determined both by the crop *per se* and the environment (Wang, 2008). This wide range of variation in yield is, thus, attributed to various factors such as variety, farming practices, inputs and location. This indicates that if constraints could be overcome to some extent, it would be possible to increase the yield. It was noted that the trend of increased productivity was higher in Zoba Debub than in Zoba Maekel during the on season cultivation period. This observation can be ascribed to the factors including topography, water availability, cultivars used and access to resources. The reason why the yield is relatively higher during on-season can further be explained by the fact that there is less pest pressure, especially insect pests during the rainy season and plants particularly the late maturing cultivars get enough water to reach maturity without being disrupted. Especially, in Zoba Maekel farmers mentioned that they have shortage of water during the off-season period. This finding is supported by majority of the respondents. It was reported earlier by Bereketsahay (2000) that the locally available potato varieties produce only 5 tons

per ha, but they are consistent in terms of maintaining that level of production. Contrasting to our findings, Emana and Nigussie (2011) reported slightly higher yield was obtained from irrigated crops in Ethiopia. This can be due to the different varieties and cultural practices used as well as the varied pest pressure levels.

3.3.6 Mode of consumption, marketing and transportation

3.3.6.1 Mode of consumption

To date there is no potato processing plant in Eritrea. Thus, the harvested potato for home consumption is served as cooked (stewed) and/or boiled forms with a limited amount being used as salad. It is probably because of this reason that the crop has remained a common staple food prepared in avariety of forms in Eritrean dishes. It was reported by Tesfaye *et al*. (2010) that potato is a common menu item in most regions of the East African region. Compared with other staple crops in the region, potato has gained importance in the last 20 years (CIP, 2011). But the mode of consumption varies from country to country. In Eritrea and Ethiopia, for instance, consumption is in the form of sauce in mixture with other spices whereas, consumption of boiled potato is most dominant cultural dish in the rest of the countries in the region (Tesfaye *et al*., 2010). This is of essence, as the first crop that can be harvested after the onset of the rainy season is potato, especially, in rainfed systems. In situations of food insecurity this makes potato an important 'hunger breaking' crop to assure staple food before grains can be harvested (Gildemacher, 2012).

3.3.6.2 Potential marketing outlets

The farmers interviewed in this study use a variety of potential outlets, indicating that they were highly market oriented, although some few farmers produce for home consumption. The farmers tended to market a large proportion via wholesalers (78.3%) and/or retailers (27.5%). Few of them also sold directly to consumers (18.8%). This figure could further be elaborated at Zoba level. From this analysis it became clear that

95.2 % of the farmers in Zoba Debub and 51.9% from Zoba Maekel used the wholesale marketing outlet (Figure 3.11). Few (5%) of the growers used the retailer and/or direct to consumers marketing channel in Zoba Debub. This is because majority of the growers in this Zoba were semi-commercial, thus, likely to make deals with wholesalers than otherwise. On the other hand, a very significant number of growers in Zoba Maekel transported and sold their produce themselves directly in the market place. Consequently, 59.3% and 46.3% sold their product to retailers and directly to consumers in the market place, respectively. This mode of marketing was insignificant in Zoba Debub growers. However, all the farmers were aware that potato grown during the off-season and sold directly to ultimate consumers fetched premium prices.

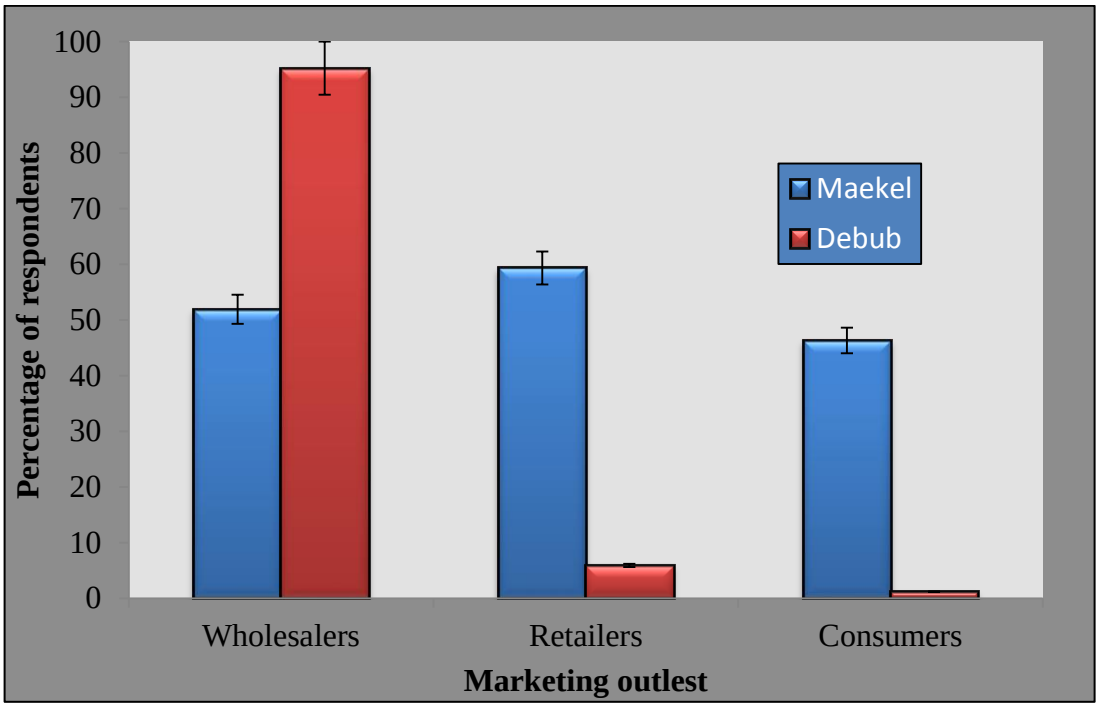


Figure 3.11: Marketing outlets of potato

3.3.6.3 Produce transportation

Most of the farmers transported their products to the destination using their own transportation means (motor or animal draft) or hiring when required. Over 45% of

farmers used private followed by hired (over 30%) transport systems. Some of them used public transport, especially in Zoba Maekel. (Table 3.10). The results further showed that relatively higher number from Zoba Maekel used animal draft for transportation. In Ethiopia, most ware potato farmers took their produce to village markets often on horseback or hand carried, where it was sold to wholesalers (Emana & Nigussie, 2011; Gildemacher, 2012). Comparatively the marketing sytem in Eritrea and Ethiopia is traditional than in Kenya and Uganda where they have better developed marketing system. On average the growers in the farms visited transported their produce for a distance ranging from 0 (farm gate) to 88 km (market), with a mean of 15 km. (Figure 3.12). The chisquare analysis indicated that, there was no statistical difference in the mode of transportation across the two Zobas (Table 3.10). The minimum and maximum marketing distance in Zoba Maekel was 0 Km and 31 Km, respectively. This is the the smallest Zoba with an average radius of 30 Km and their main market is the capital city, Asmara. Whereas in Zoba Debub the minimum and maximum distance was 6 and 88 Km, respectively. For some of the growers the capital city, Asmara, remained to be the main market place, especailly the semi-commercial growers. This is because the main potential buyers are located in the capital and it is worth transporting all the way to the capital to fetch premium prices.

Figure 3.12: Potato sack packing and transportation to the final destination.

Table 3.10: Potato transportation options to the final destination

	Transportation of produce by respondents (%)			
Zoba*	**Public vehicle**	**Private vehicle**	**Hired vehicle**	**Animal Draft**
Maekel	27.8	40.7	24.1	7.4
Debub	13.1	47.6	36.9	2.4

*ρ= 0.210 => ρ>α (0.21>0.05) thus the Ho is accepted.

3.3.7 Constraints affecting potato cultivation in Eritrea

The finding of this study revealed that lack of agricultural inputs such as pesticides, fertilizers, application equipments followed by availability and cost of quality seeds were considered to be the main bottlenecks. This remained to be a common problem adversely affecting more than 97% of the respondents. On the other hand, transportation access followed by availability of water and market are considered opportunities that encourage growers. For in depth understanding of the situation it was deemed necessary to investigate the issue across the two zobas.

Limited availability of inputs such as quality seed tubers and chemicals were reported by all farmers as a major constraint. According to Emana and Nigussie (2011), the major potato problems in Ethiopia are insufficient supply of quality seed tubers. Further analysis of the current study showed that farmers from Zoba Maekel earmarked rainfall distribution, water and land availability as their constraints, while farmers in Zoba Debub consider pest pressure and availability of fuel as their constraints following to the input availablty and cost (Figure 3.13). This variation in ranking is attributed to the different farming practices and scale of cultivation. The indepth analysis also revealed that farmers from Zoba Maekel have market, transportation and labour availability thus encouraging them to further expand their productivity. While, growers from Zoba Debub consider easy transportation acess and water availability followed by marketing as their encouraging opportunities (Figure 3.13).

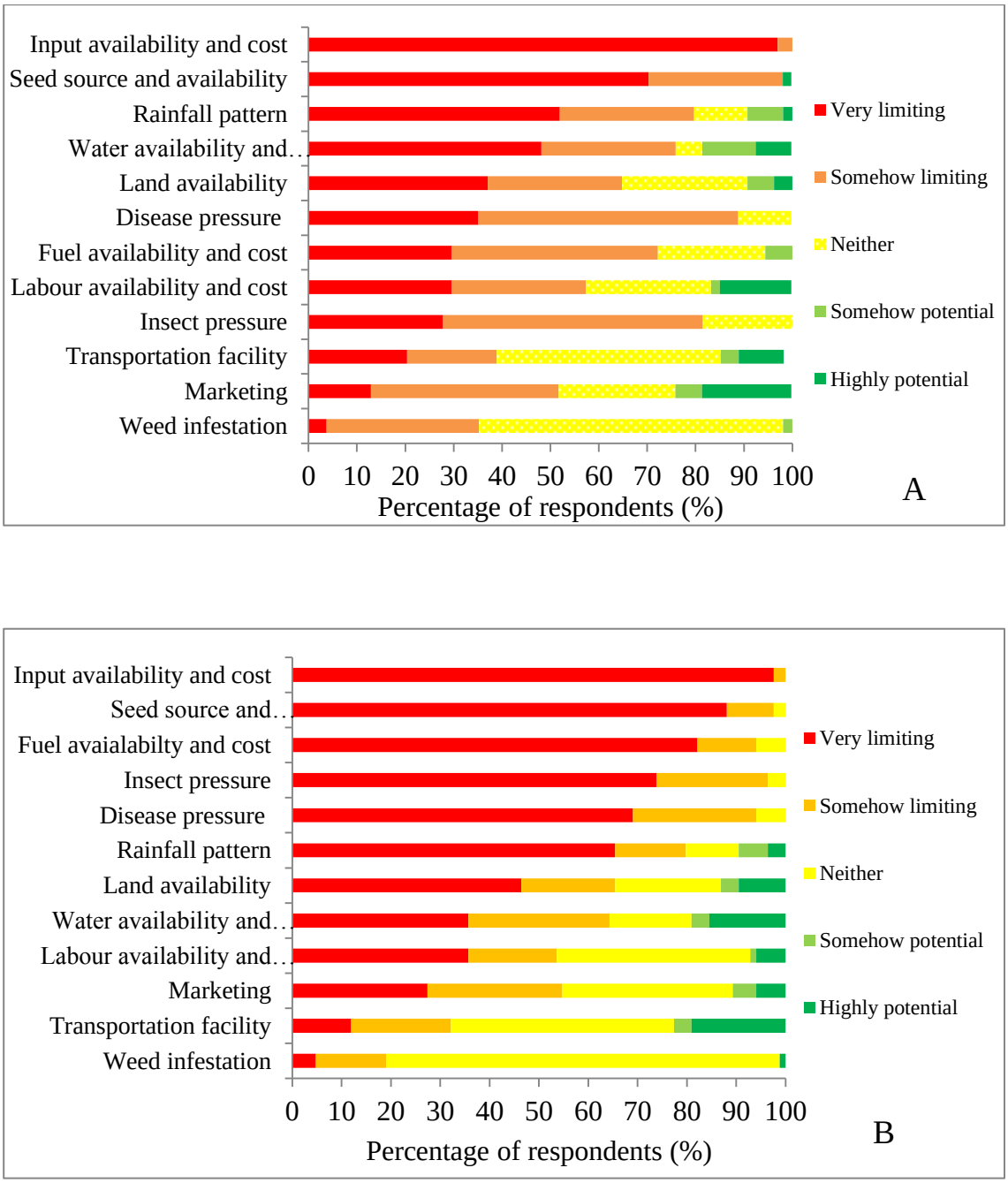


Figure 3.13: Major constraints affecting potato cultivation in Eritrea , ("A" Maekel & "B" Debub) .

3.4. Conclusion

The study revealed that potato was widely grown in Eritrea, with considerable differences in most of the farming practices between the two zabas. There was an acute shortage of farm inputs, especially seed, fertilizers and pesticides resulting in the proliferation of informal distribution systems across the country. Thus, farmers were obliged to use own seed for several generations. Cut worm, aphids and potato tuber moth (PTM) were the main insect pests infesting the potato crop while late blight, common rust and *Fusarium* wilt infection were the main diseases in the visited villages. Farmers control the pests using the chemicals followed by cultural methods. Availability and cost of inputs and availability of quality tuber seeds were the main constraints affecting potato production in Eritrea. The constraints varied considerabley across the two zobas. The study disproves the general belief that potato farming practices, cultivars used and constraints and potentials are the same in the two zobas. Specific intervention should, therefore, be formulated for each region to address the problem, thus optimize potato productivity in the country.

CHAPTER FOUR

CHARACTERIZATION OF POTATO (*SOLANUM TUBEROSUM* L.) CULTIVARS GROWN IN ERITREA USING MORPHOLOGICAL DESCRIPTORS

Abstract

Potato is a very important crop in Eritrea. However, very little is known about the genetic diversity of farmers' and imported cultivars grown in the country. Hence, the current study was proposed to characterize the potato cultivars. A total of 33 morphological descriptors comprising both qualitative and quantitative were used to characterize 17 farmers' cultivars and 4 imported cultivars. Plants were grown in two geographically different locations (Hemelmalo Agricultural College (HAC) and Asmara). The potato cultivars grown at HAC emerged early (24.52 days) and also reached maturity early (94.84 days) as compared to those grown at Asmara with 43.77 and 123.59 days, respectively. The first four components explained about 85% of the total variability. The bi-plot analysis classified the cultivars into four groups with G-I (8 farmer's); G-II (6 farmers' and 3 imported); G-III (2 farmers' and 1 imported) and G-IV (1 farmers') while the UPGMA clustering grouped them into three where G-II and G-III were merged together at 92% similarity. The grouping helped to identify materials that share the same characteristics and that are closely related. It was noted that there was no distinct relationship between the cluster groups and geographic origin of the cultivars. Some farmers' cultivars sharing the same name were clustered in different group indicating they were different cultivars. Mean deviation of variables for each cluster group from the total mean indicated that G-III followed by G-I showed negative deviation in most of the recorded yield related traits. G-I was particularly affected by the presence of two inferior cultivars in the group. On the other hand, G-II showed relatively positive deviation from the total mean and can be recommended for use as parent for future breeding program in Eritrea.

4.1 Introduction

Potato cultivation has a long history in Eritrea during which farmers have adopted a number of landraces, but little is known about their identity. Understanding the genetic diversity of a species can assist in the analysis of the taxonomic structure of potential populations for crop improvement (Afuape, Okocha, & Njoku, 2011). The correct identification of a cultivar can be used to certify its pureness as a genotype (Rosa *et al*., 2010); although many cultivars share the same traits.

A number of approaches are commonly used for characterization of cultivars including pedigree, morphology, agronomic performance, biochemical, and molecular (DNA-based) data (Mohammadi & Prasanna, 2003). The typical approach to variety identification involves the observation and recording of morphological characters or descriptors (Nováková *et al*., 2010). Morphological assessment is based on phenotypic characteristics of a plant species that determine diversity and similarity between and within populations. These descriptors are traits such as leaf type, tuber shape and flower colour which can be analyzed during different developmental stages of the crop. According to Fongod *et al*. (2012) morphological descriptors could be suitable for use in distinguishing accessions. Previously, Huaman, Salas, Gomez, Panta, & Toledo (2000) reported reduction of >75% in the number of accessions collected from farmers in Latin America after characterizing the accessions using 25 morphological descriptors. Several studies using morphological descriptors have been conducted on potato (Ahmadizadeh & Felenji 2011; Arslanoglu *et al*. 2011; Felenji *et al*. 2011) and other crops e.g. sweet potato (Afuape *et al*. 2011; Fongod *et al*. 2012; Maquia *et al*. 2013; Tairo *et al*. 2008), chili (Del *et al*., 2007), peanut (Upadhyaya, Ortiz, Bramel, & Singh, 2003), and rice (Gana *et al*. 2013; Sinha *et al*. 2013).

Few studies have been conducted on the genetic diversity of potato in Eritrea, to characterize and identify both farmers' cultivars and imported varieties. Farmers' potato cultivars are widely known by names based on flower colour or place of

origin/cultivation as *carneshim, Israel, shashemanie, Asela, America*. Similar naming and duplication problem was reported by (Tairo *et al*., 2008) in sweet potato grown in Tanzania. This makes it difficult and complicated to collect, identify and classify cultivars while avoiding duplication as many different local names are conferred to the same cultivars and *vice versa*. In the absence of this valuable varietal identification, it becomes a major challenge to conduct and evaluate any varietal performance and to select and improve suitable farmer-preferred varieties.

The objective of this study was to assess the nature and magnitude of diversity among the potato cultivars currently grown in Eritrea using morphological descriptors.

4.2 Materials and Methods

4.2.1 Plant materials

Twenty one potato cultivars (farmers' and imported) were collected during the diagnostic survey study (Table 4.1). The tuber seeds were allowed to sprout and later planted in two locations under farmers' conditions to determine similarity and diversity among them with respect to their morphological characters.

4.2.2 Site description

The first site was at the experimental field of Hamelmalo Agricultural College (HAC), which is located 13km North of Keren on the Keren-Nakfa road (Figure 4.1). The altitude of the area is about 1330 m.a.s.l with 15'53 N and 38'26 E coordinates. The average temperature and rainfall during experimental time (January-May, 2014) is shown in Table 4.2. The second site was in the highland part of the country, capital city, Asmara which is located at 2363 m.a.s.l of 15'20N and 38'56 E with an average temperature and rainfall shown in Table 4.2. Soil composition in both sites was analyzed in the soil laboratory of the National Agricultural Research Institute [NARI] (Table 4.3).

Table 4.1: List and sources of potato cultivars used in this study

Accession No.	Common Name	Village	Sub-Zoba	Zoba	Source
1	Yeha	Geremi	Serejeka	Maekel	Farmers
2	Tsaeda_Embaba_I	Afdeyu	Serejeka	Maekel	Farmers
3	Keyh_Embaba_I	Afdeyu	Serejeka	Maekel	Farmers
4	Tsaeda_Embaba_ II	Adiregit	Serejeka	Maekel	Farmers
5	Carneshim	Adiregit	Serejeka	Maekel	Farmers
6	Shashemanie_I	Mendefera	Mendefera	Debub	Farmers
7	Zafira_I	SelaeDaero	Galanefhi	Maekel	Farmers
8	Round_Sudan	SelaeDaero	Galanefhi	Maekel	Farmers
9	Oval_Sudan	SelaeDaero	Galanefhi	Maekel	Farmers
10	Keyh_Embaba_II	Debarwa	Debarwa	Debub	Famers
11	Tsaeda_Embaba_III	Debarwa	Debarwa	Debub	Farmers
12	Banba	Halhale	Debarwa	Debub	NARI
13	Baren	Halhale	Debarwa	Debub	NARI
14	Orla	Halhale	Debarwa	Debub	NARI
15	Slaney	Halhale	Debarwa	Debub	NARI
16	Shashemanie_II	Adi-Blay	Emnihaili	Debub	Farmers
17	Keyh Embaba_III	Adi-mongonti	Mendefera	Debub	Farmers
18	Ajiba	Adi-mongonti	Mendefera	Debub	Farmers
19	Zafira_ II	Mendefera	Mendefera	Debub	Farmers
20	Safira	AdiInadi	Mendefera	Debub	Farmers
21	Grandinaine	Adi-mongonti	Mendefera	Debub	Farmers

Table 4.2: Average monthly temperature and rainfall of the two sites during the experiment.

	Temperature (^{o}C) 2014				
Site	**January**	**February**	**March**	**April**	**May**
HAC	22	27	25	26	28
Asmara	14	14	17	18	18
	Rainfall (mm) 2014				
HAC	0.0	0.0	0.0	12.9	12.2
Asmara	0.0	0.0	33.6	49.8	37.1

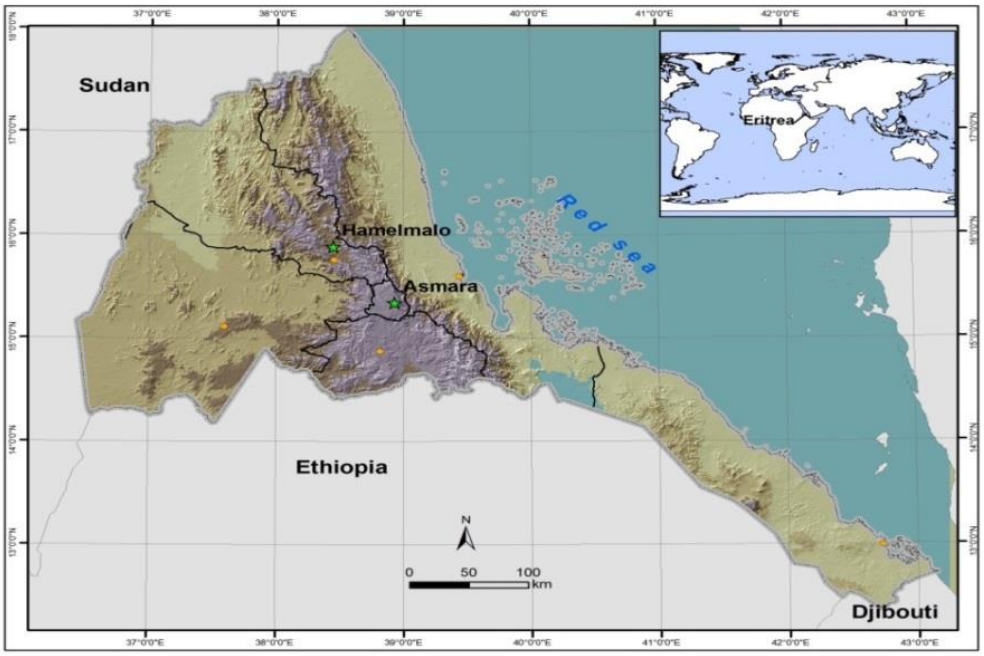


Figure 4.1: Map of the experimental sites, HAC and Asmara (Curtesy: Selam Tesfay).

Table 4.3: Soil chemical properties of HAC and Asmara sites.

Site	TN (%)	P (ppm)	OM (%)	EC dS/cm	pH	Na	Ca	Mg	K	CEC
						Cmol (+)/kg				
HAC	0.05	2.03	0.96	0.13	8.20	0.68	18	5	0.18	24.9
	Very low	Very low	Very low	Non saline	Moderately alkaline	Moderate	High	High	Very low	Moderate/ High
ASM	0.03	16.2	0.52	0.77	7.8	1.2	49	12	0.93	64.2
	Very low	low	Very low	Non saline	Slightly alkaline	High	Very High	Very High	Moderate	Very High
Optimum levels	0.15-0.25	>21	1.7-3	4-8	5-5.8	0.3-0.7	5-10	1-3	0.3-0.7	>20

4.2.3 Experimental design

The experiment was laid out in a randomized complete block design with three replications each. Planting was made in furrows at inter- and intra-row spacing of 0.70 and 0.40 m, respectively. Each cultivar was sown in three rows using six tubers per row, giving 18 plants per plot and 63 plots per site.

The land for use in this experiment was prepared in December 2013, using a tractor followed by manual harrowing, leveling and making of furrows. At planting time, Di-Ammonium Phosphate fertilizer was applied at the rate of 200kg/ha. One month after emergence, Urea fertilizer was applied at the rate of 150 kg/ha. Water was applied to the experimental plots using furrow-irrigation at one week (HAC) and two weeks (Asmara) intervals.

4.2.4 Data collection

Data for morphological traits were recorded on four randomly selected plants from the middle of each plot as per the descriptors reported by (Huaman, Williams, Salhuanand, & Vincent, 1977; Mackay, Hijink, & Mix, 1985) at flowering time. A total of 33 descriptors comprising of vegetative, flowering pattern and reproductive phases were used (Table 4.4). The qualitative morphological characters were performed by numerical coding of each character using qualitative multi-status criteria (from 0 to 9), whereas for the quantitative traits, data collection is described below. Detailed information on the descriptors and coding is availability in Appendix (4.1).

Plant height (PH): Plant height (cm) was taken as the length from the ground level to the tip of the plant using a measuring scale.

Stem thickness (ST): Stem thickness at the base (5 cm above ground) was measured using a digital Vernier Caliper in cm.

Number of primary stems (No PS): main shoots emerging from the tuber were counted and determined as primary stems.

Days to emergence (Emer DAP): Days taken to emerge were counted when 50% of the plants in a plot had emerged.

Emergence % (Emer %): number of emerged seedlings divided by total plants per plot was recorded multiplied by 100.

Days to flowering (Flow DAP): counted as the number of days from emergence to flowering and recorded when 50% of the plants are flowering.

Number of flowers (No. Flow): Total number of flowers that blossomed per plant was counted.

Tuber characteristics: number of tubers per plant counted, tuber size was measured using digital Venire Caliper in cm, total yield per plant was determined using digital balance in grams.

Table 4.4: Vegetative, flowering and reproductive descriptors used in this study

Vegetative	Flowering	Reproductive
Days to emergency	Days to flowering	Tuber diameter/size (T_size)
Emergence % (Emer_%)	No of flowers per plant	Primary tuber Skin color (PTSC)
No of primary stems (No PS)	Primary Flower Color (PFC)	Intensity of primary skin color
Stem color (SC)	Secondary Flower Color (SFC)	Secondary tuber skin color
No of interjected leaf lets (No inter	Distribution of SFC (Diss. SFC)	Distribution of STSC
No of lateral leaf lets (No later	Flower degree (Flow_dg)	Primary Tuber Flesh Color
Plant Height (PH)		Secondary Tuber Flesh Color
Stem Thickness (ST)		Tuber shape (T_shape)
Stem Wing (SW)		Tuber Eye Depth (T_ED)
Growth Habit (GH)		Skin texture (S_texture)
Branching Habit (BH)		Tuber set (T_set)
Primary Sprout Colour (PSC)		Tuber weight (T_wt)
Secondary Sprout Colour (SSC)		Maturity time (Maturity)
Distribution of SSC (Diss.		
Vigorousity (RBS)		

4.2.5 Data analysis

The qualitative and quantitative data collected were analyzed using GenStat (12th Edition) statistical software. In case of quantitative data, analysis of ANOVA was carried out to determine any significant variation among the studied cultivars.

Standardization of the data by means of the coefficient matrix function was made and then subjected to multivariate analysis of principal component analysis (PCA), correlation coefficient matrix, bi-plot and cluster analysis using SPSS (Version 20) and GenStat (12th Edition) according to (Harding & Payne, 2012). The phenotypic correlation coefficient ® values were calculated to measure the relationship between two sets of variables and correlation matrix was generated. Eigen values, percent variance, variance and cumulative percentage of each of the extracted factors were calculated and PCA analysis done on the basis of major factors. To complement PCA, single linkage (nearest neighbor) clustering method employing Euclidean test, similarity matrix, Agglomerative, Hierarchic and Non overlapping (SAHN) technique was used to yield a dendrogram. Scatter plot using prediction bi-plots were employed to provide graphical description of the data distribution to observe relation between variables and points (cultivars) according to (Malik *et al*., 2014). The cosine of the angle between the vectors of two traits measured the similarity or the correlation between them relative to their variation among cultivars. In other words, no angle (0°) means +1, an angle of <90° suggests a positive correlation, no correlation is if an angle of 90° between them is observed, where as an angle >90° indicates negative correlation, and an angle of 180° represents a correlation of -1.

4.3 Results and Discussions

4.3.1 Plant growth characteristics

The data collected from the field in both sites on morphological characteristics indicated that there was a significant locational effect on the growth and performance of the

plants. Data collected on the emergence date, plant branching habit, days to flowering, numbers of flowers, number of primary stem, stem thickness, growth habit, leaf interject, number of lateral leaves, maturity time and over all yield quality and quantity showed a significant difference between the two sites (Table 4.5). This indicated that morphological characters of plants are strongly affected by the environment and soil type. According to Crawford (2000), morphological descriptors unlike the molecular markers are not free from environmental and pleotropic effects. The results showed that potatoes grown in HAC took fewer days to emerge (24.52) and reach maturity (94.84) as compared to those grown in Asmara 43.77 and 123.59 days, respectively. This could be attributed to the climatic conditions of the two sites, where HAC is subtropical advancing the growth rate at the cost of yield quality and quantity (Table 4.5). It was reported by (Waniale, Wanyera, & Talwana, 2014) that there were significant differences in all quantitative traits measured among the Mungbean varieties planted in two different locations in Uganda for characterization. In the current experiment, mean average of all the parameters in the two sites was used to calculate the PCA, correlation matrix and dendrogram to minimize environmental effect, although a separate cluster analysis and grouping of the materials grown at Asmara and Hemelmalo was also conducted (Table 4.6).

Table 4.5: Statistical summary of the variables in the two sites and their mean.

Variables	Sites		Statistical summary	
	HAC	Asmara	Mean	LSD
Emergence Date	24.52	43.77	33.66	0.96**
Branching Habit	1.07	1.40	1.23	0.09**
Growth Habit	1.57	1.84	1.75	0.11**
Stem Thickness	8.22	8.68	8.40	0.34*
Plant height	22.02	21.69	21.86	1.14^{NS}
No. of Primary Stems	3.23	2.30	2.78	0.27**
Flowering Date	41.07	73.74	55.65	1.95**
Flowering degree	2.68	4.58	3.61	0.07**
No. of Flowers	2.30	1.86	2.03	0.12**
Stem wing	2.06	1.70	1.90	0.12**
Leaf interject	1.68	2.00	1.84	0.04**
No. of lateral leaves	4.03	3.94	3.99	0.08*
Maturity time	94.84	123.59	108.30	1.84**
Tuber set	8.35	9.85	8.99	0.83**
Tuber Size	38.00	40.20	39.42	1.21**
Tuber weight	0.37	0.49	0.43	0.04**

** highly significant at $\rho < 0.01$; * significant at $\rho < 0.05$ NS= not significant

4.3.2 Correlation coefficient matrix

Pearson's correlation is a measure of strength of linear relationship in between two variables (Sinha *et al*., 2013). In the current study, the correlation coefficient analysis helped to decide how many descriptors to select and remove the ineffective traits. The preliminary analysis identified that about 50% of the descriptors used contributed no significant variation to discriminate the cultivars, thus were removed from the analysis.

Table 4.6: Morphological characteristics of the potato cultivars as explained by quantitative traits recorded in the two sites.

Cultivars	Asmara								HAC							
	PH (cm)	ST (cm)	No PS	T_wt (Kg/plt)	Tuber set/plt	T_Size (cm)	Maturity (Days)	Cluster	PH (cm)	ST (cm)	No PS	T_wt (Kg/plt)	Tuber set/plt	T_Size (cm)	Maturity (Days)	Cluster
Yeha	22.1	7.5	3.5	0.311	14.08	31.0	132.0	GI	28.1	7.8	5.3	0.386	15.17	35.1	92.3	GI
Tsaeda_Embaba_I	23.1	7.6	3.1	0.328	19.42	27.3	131.0	GI	28.7	8.0	5.3	0.304	14.25	32.5	94.3	GI
Keyh_Embaba_I	16.4	6.9	1.7	0.163	6.00	34.3	116.3	GI	16.4	6.1	2.2	0.105	5.50	32.2	72.0	GIII
Tsaeda_Embab_ II	24.8	8.2	4.3	0.472	18.67	30.3	132.0	GI	27.6	7.4	5.6	0.384	13.33	34.5	92.7	GI
Carneshim	22.2	10.8	2.0	1.050	6.92	56.8	126.7	GI	25.8	10.6	3.5	0.671	6.42	52.6	92.7	GII
Shashemanie_I	22.2	7.0	3.3	0.506	18.58	32.7	133.3	GI	33.0	7.7	5.3	0.406	13.08	40.0	93.0	GI
Zafira_I	20.6	7.4	1.8	0.364	6.67	39.4	122.3	GIII	20.9	8.0	3.1	0.408	6.67	43.3	90.0	GII
Round_Sudan	21.5	9.5	1.3	0.363	6.50	40.8	108.7	GI	12.8	9.2	1.2	0.363	5.33	41.8	95.0	GII
Oval_Sudan	22.5	11.0	2.1	0.413	6.83	38.4	128.3	GIII	22.1	9.7	2.7	0.254	4.75	32.7	84.7	GII
Keyh_Embaba_II	33.1	8.2	3.0	0.642	17.00	36.2	106.7	GII	35.9	7.6	5.5	0.560	16.00	34.1	89.0	GI
Tsaeda_Embaba_III	23.3	11.4	1.6	0.816	7.33	52.3	124.7	GI	22.5	9.8	2.0	0.633	7.50	41.4	95.67	GII
Banba	19.5	8.1	2.5	0.788	7.08	50.6	126.0	GI	19.8	8.2	2.2	0.292	4.50	41.4	111.0	GII
Baren	17.6	8.8	2.6	0.386	7.00	42.5	126.0	GI	16.3	9.3	2.4	0.393	4.83	40.4	117.7	GII
Orla	19.3	7.5	2.6	0.236	5.50	38.7	113.7	GIII	18.2	8.9	1.8	0.205	4.75	36.5	92.3	GII
Slaney	18.8	8.9	2.2	0.538	6.17	46.9	121.3	GI	16.3	9.2	3.8	0.351	5.00	38.8	114.7	GII
Shashemanie_II	21.3	10.2	2.0	0.613	18.33	35.4	128.7	GI	36.2	7.9	4.3	0.560	18.33	38.1	93.0	GI
Keyh Embaba_III	18.8	8.0	1.5	0.272	10.67	35.0	123.3	GI	11.1	4.6	2.2	0.148	7.17	20.0	62.3	GII
Ajeba	18.3	7.0	2.7	0.357	7.23	38.7	99.3	GII	18.9	6.7	3.1	0.348	5.33	41.9	87.0	GII
Zafira_ II	22.3	10.1	1.4	0.622	4.25	53.6	128.0	GIII	18.2	9.9	1.8	0.362	5.67	39.6	115.0	GII
Safira	20.9	7.4	2.3	0.286	4.75	42.0	117.3	GI	16.8	6.7	2.7	0.333	5.17	41.4	87.0	GII
Grandinaine	25.1	9.8	1.5	0.662	6.70	50.8	129.3	GI	15.6	8.5	1.8	0.341	5.00	41.0	116.3	GII
Grand mean	**21.6**	**8.6**	**2.3**	**0.492**	**9.79**	**40.7**	**122.6**		**21.9**	**8.2**	**3.2**	**0.372**	**8.27**	**38.1**	**94.7**	
LSD	**5.1**	**1.5**	**0.8**	**0.210**	**4.21**	**5.9**	**6.20**		**4.5**	**1.5**	**1.5**	**0.077**	**1.24**	**4.6**	**8.1**	

PH = plant height; ST = stem thickness; No. PS = number of primary stem;, T_wt = tuber weight., T_set = tuber set; and T._size = tuber size;

Out of the total 33 descriptors used, 16 exhibited strong contribution to explain variation among the studied materials and were used for further classification analysis. It was reported by Felenji *et al*. (2011) that the factors which justify more percentage of variations are importance for further study. The pairwise correlation among the identified 16 traits was thus generated (Table 4.7). The table shows positive and negative correlation between the variables along with their magnitude. Generally, all the flowering patterns exhibited a strong relationship to each other.

Emergence day showed a strong positive correlation with stem thickness (0.62) whereas strong negative correlation with number of primary stems (-0.72) and growth habit (Table 4.7). Similarly, number of primary stem showed strong positive correlation with plant height (0.74) and tuber set (0.82). Tuber set had strong positive correlation with number of primary stem (0.82), plant height (0.82), flower degree (0.67) but negative correlation with tuber shape (-0.69). It can then be inferred from the current results that an accession having more and longer stems are likely to produce more tubers, but usually inversely relate to yield or tuber weight. This agrees with previous findings by Felenji *et al*. (2011) and Ahmadizadeh & Felenji (2011) where they reported positive correlation between number of stems, plant height and tuber numbers. Similarly, Rashidi, (cited in Felenji *et al*. 2011) reported that number of tubers had a high correlation with number of stems produced. Yet, previously it was reported by Lopez *et al*. (1987) that there was a strong correlation between plant height and number of tubers produced. In the current study, tuber weight was strongly correlated with the tuber size and stem thickness (Table 4.7), while negatively correlated with tuber set (numbers). This is in accordance with the report made by (Felenji *et al*., 2011). It can also be inferred that accessions with higher stem thickness and tuber size are associated with high yields. The negative correlation between tuber weight and tuber number is ascribed to the fact that the larger the number of the tubers per plant produced, the smaller the size of each, which can be related to the strong competition for resources. Previously, Felenji *et al*. (2011) drew the same conclusion out of their findings.

There was moderate negative correlation between stem thickness and number of primary stems. In other words, the more the primary stems per plant the less the thickness. It can, therefore, be concluded that accessions with thick stem diameter were associated with bigger tuber size and thus higher yields than accessions with many primary stems but thin stem size.

Table 4.7: Correlation coefficient matrix among the 16 descriptors.

Variables	Emer_DAP	SW	GH	No_PS	PH	ST	Flow_DAP	SFC	Dis_SFC	Flow_dg	No_ flow	Maturity	T_ shape	T_size	T_set
SW	-0.22	1.00													
GH	-0.65**	0.02	1.00												
No_PS	-0.72**	0.26	0.38*	1.00											
PH	-0.38*	0.06	-0.05	0.74**	1.00										
ST	0.62**	0.20	-0.54**	-0.29*	0.09	1.00									
Flow_D	0.28	-0.01	-0.15	0.12	0.12	0.04	1.00								
SFC	0.00	-0.36*	-0.09	0.20	0.37*	-0.09	0.70*	1.00							
Dis_SF	0.11	-0.15	-0.07	0.26	0.31*	-0.05	0.91*	0.89*	1.00						
Flow_	-0.02	-0.06	0.03	0.47**	0.39*	-0.10	0.90*	0.75*	0.92*	1.00					
No_flo	0.16	-0.06	-0.04	0.35*	0.29*	-0.02	0.90*	0.64*	0.88*	0.95**	1.00				
Maturit	0.29	0.27	-0.09	0.10	0.08	0.50*	0.31*	-0.01	0.18	0.22	0.25*	1.00			
T_shap	0.53**	0.13	-0.42	-0.58**	-0.29*	0.62*	-0.33*	-0.45*	-0.45*	-0.54**	-0.40*	0.11	1.00		
T_size	0.41*	0.12	-0.39*	-0.43*	-0.17	0.63*	-0.15	-0.17	-0.26*	-0.37*	-0.33*	0.34	0.79**	1.00	
T_set	-0.49**	0.02	0.19	0.82**	0.82*	-0.23	0.39*	0.49*	0.53*	0.67**	0.56*	0.04	-0.69**	-0.56**	1.0
T_wt	0.09	0.13	-0.37*	0.12	0.50*	0.63*	0.14	0.24*	0.15	0.13	0.05	0.33	0.37*	0.67**	0.1

Emer. DAP = emergence day after planting; SW= stem wing; GH= growth habit; No. PS = number of primary stem; PH = plant height; ST = stem thickness; Flow DAP = flowering day after planting; SFC= secondary flower colour; Dis_SFC= distribution of SFC; Flow_dg=flower degree; No_flow= number of flowers per plant; T-shape= tuber shape; T._size = tuber size; T_set = tuber set; and T_wt = tuber weight.

** highly significant at $\rho<0.01$; * significant at $\rho<0.05$

4.3.3 Principal Component Analysis (PCA)

The current PCA (Table 4.8) shows the importance and variation contributed by each of the 16 variables identified. Based on the initial Eigen value ≥ 1 scored in the current study, four components were selected. The finding is further supported by the scree plot result. The identified traits in the components exhibited significantly variation among the cultivars based on the morphological expression, which can be used for selection purposes. Afuape *et al*. (2011) reported a total variation of 76% by the first three axes among 21 sweet potato landraces using 17 traits. The total variation of 85% explained in the current study by the first four components is an indication that there is strong and rich genetic variation among the cultivars that can be exploited for breeding purpose. On the other hand Tairo *et al*. (2008) found only 52.5% variation explained by the first five components in sweet potato grown in Tanzania which indicated very low genetic variation among the genotypes used.

The separate PCA of the two locations gave comparable results, although, the yield related characters and plant height were explained by PCA1 at HAC while by PCA2 at Asmara. Moreover, the percentage of variability explained by the first four components in the two sites was more or less similar with 84% at Asmara and 81% at HAC. When data were pooled together, PCA1 with eigenvalue of 6.0 contributed 37.50% of variation among the observed 21 potato accessions. The traits accounting for this component were flowering day, secondary flower colour (SFC), distribution of SFC, flower degree and number of flowers per plant (Table 4.8); PC2 with 3.85 Eigenvalue contributed 24.08% of the total variation relating to tuber shape, tuber size, tuber weight, growth habit and stem thickness; PC3 corresponded to emergence day, plant height, number of primary stem and tuber set. It can thus be inferred that PCA1 is associated with flower pattern of the crop while PC2 is related to yield components. PC3 associated with vegetative growth of the crop; hence, selecting genotypes based on PC3 would have more vegetative growth. Afuape *et al*. (2011) reported that number of marketable roots, total number of roots, weight of marketable roots, weight of

unmarketable roots, total root weight, root length and root incidence and severity *Cylas spp* explained more variation and had been important traits to identify desired parental lines of sweet potato for breeding. Moreover, Felenji *et al*. (2011) reported that out of 80.05% variation explained by the first three factors 33.29% was accounted for by the first factor which was attributed to yield variation changes, tuber weight, harvest index and biological yield. The authors thus concluded that this factor was an effective factor in increasing yield for the cultivars.

Table 4.8: PCA of the 16 descriptors used to evaluate the 21 potato cultivars.

Variables	Principal Components (PCs)			
	1	2	3	4
Emergence date after planting (Emer DAP)	0.264	0.583	-0.684	-0.055
Stem Wing (SW)	-0.156	0.011	0.147	0.814
Growth Habit (GH)	-0.134	-0.706	0.183	0.187
No Primary Stems (No PS)	0.183	-0.337	0.843	0.257
Plant Height (PH)	0.205	0.177	0.914	-0.051
Stem thickness (ST)	0.012	0.853	-0.083	0.289
Flowering days after planting (Flow DAP)	0.963	0.050	-0.060	0.114
Secondary Flower Color (SFC)	0.785	0.071	0.257	-0.392
Distribution of _SFC (Diss. SFC)	0.958	-0.005	0.144	-0.085
Flower degree (flow dg)	0.936	-0.115	0.269	0.065
No of flowers per plant (No flow)	0.938	-0.075	0.103	0.106
Maturity	0.287	0.348	-0.030	0.692
Tuber shape (T_shape)	-0.427	0.701	-0.373	0.111
Tuber size (T_size)	-0.270	0.813	-0.180	0.161
Tuber set (T_set)	0.477	-0.246	0.794	-0.008
Tuber weight/yield (T_wt)	0.075	0.813	0.462	0.090
Eigen-value for each PC	**6.0**	**3.85**	**2.37**	**1.32**
Variation in percentage (%) for each PC	**37.50**	**24.08**	**14.08**	**8.25**

The fact that more variation (37.5%) followed by 24.08% was explained by PCA1 and PCA2, respectively, thus suggested that selection of the materials using these components would be sufficient and is recommended. This indicates that PCA can be used to identify the contribution of each morphological characteristic from the cultivars to form a group or cluster. It, thus, helps to identify desired traits contained by each cultivar/group for further breeding activity.

4.3.4 Cultivars vs Trait Bi-plot (PC Bi-plot)

A principal component bi-plot of the 21 studied potato cultivars and the 16 traits were carried out to show the underlying relationships among the cultivars, cultivars with traits and between the traits. The graphical display of PC has been reported in various crops such as wheat (Malik *et al*., 2014); sweet potato (Afuape *et al*., 2011); cassava (Agyeman, Parkes, & Peprah, 2015); common bean (Okii *et al*. 2014). In the current study, the 21 cultivars were plotted on axes representing the two rotated components PC1 and PC2 and the results indicated that the cultivars were distributed in all the quadrants, while the traits were scattered in quadrants I, II and IV (Figure 4.2). Cultivars falling in the same quadrant are assumed to be the same or closely related (Malik *et al*. 2014). If two materials are positioned in the plot at an angle of 90º then they have no close relationship. The scatter plot matrix score clustered the materials into four main groups (GI, GII, GIII and GIV). Group I consisting of eight materials predominantly with flowering (white and/or red) coloured farmers' potato. They were characterized by intermediate emergence and intermediate maturing with more than two and long primary stems. Whereas GII consists of nine materials mainly made up of varieties of late emerging and late maturing with few and short primary stems, but relatively better yield. This group is positively associated with T_shape, T_size, T_wt, maturity and Emer_DAP, while negatively related to GH, No_PS and T_set. GIII consists of three materials (*Orla, Zafira_I* and *Oval_Sudan*) characterized by early emergence and early maturing, semi rosette growth habit and intermediate yield

quantity. On the other hand, GIV was a single material (*Ajiba*) characterized by very early maturity and lower yield quantity. Most of the materials in GII and GIII were characterized by a non-flowering pattern. This classification is not in exact, but in accordance with the cluster analysis generated employing single linkage with same data.

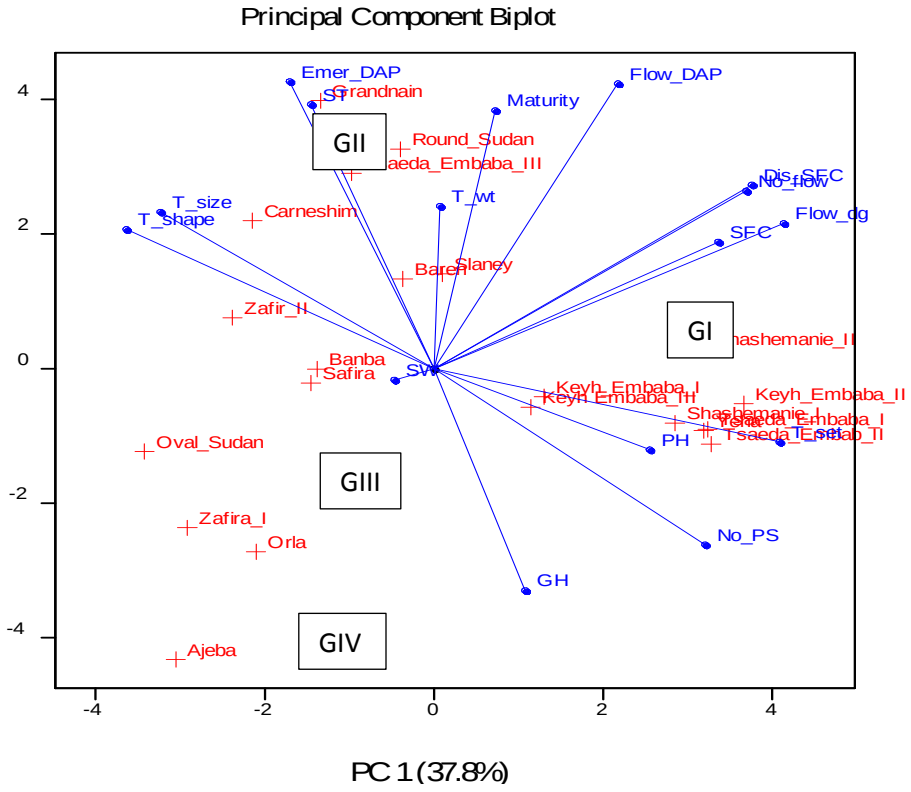


Figure 4.2: Scatter plot matrix of PC score of cultivars and descriptors.

The fact that the studied cultivars were clustered into four groups indicated that there was variability among themselves that could be exploited in selection. Especially in GII, although some cultivars like *Banba* and *Safira* showed close relationship, majority had very weak similarity as is shown from the plot. The PC bi-plot analysis, further, indicated that descriptors like ST, Emer_DAP, T_shape, T_set and most of the flowering pattern were placed at long vectors in the plot and explained most variation among the cultivars compared to PH, T_wt and maturity. Descriptors that are in the same quadrant with <90º angle means they have very close positive relationship or

otherwise. All the flowering patterns showed similarity (<90º) with PH and T_set as well with maturity and T_wt. Similarly, materials falling alongside of the trait are more explained by the respective character or trait. The plot, thus, will help to identify desired traits contained by each cultivar for further breeding activity.

4.3.5 Cluster analysis

Cluster analysis is useful for classifying different cultivars into groups based on their similarity matrix (Arslanoglu *et al*., 2011). In the current study, cluster analysis based on similarity matrix employing Euclidean test successfully classified the materials into three clusters (groups) at 92% similarity level. Group I consisted of cultivars: *Yeha, Tsaeda_embaba_II, Shahemanie_I, Tsaeda_embaba_I, Shashemanie_II, Keyh_embaba_II, Keyh_embaba_III* and *Keyh_embaba_I*; Group II consisted of: *Safira, Banba, Zafira_II, Baren, Slaney, Orla, Zafira_I, Tsaeda_embaba_III, Carneshim, Grandinaine, Round_Sudan and Oval_Sudan* while Group III: contained *Ajeba* on its own and was the most dissimilar (Figure 4.3). The grouping of cultivars in clusters reflects the relative diversity of cultivars which allows selection of the materials contained by each group as core collection (Lohani *et al*., 2012). The clustering is in agreement with the bi-plot clustering generated using the cultivar vs trait relationship, except that GII and GIII were combined in this clustering. The current cluster analysis showed that *Yeha, Tsaeda_embaba_I, Tsaeda_embaba_II* and *Shahemanie_I* were closely related cultivars with more than 98% similarity level. This could be attributed to the geographic source of the materials, although it is not applied to all materials in different groups. Considering sources of the materials are farmers, it could be inferred that some of the cultivars share the same background, although, farmers gave them different names. For instance, *Yeha*; *Tsaeda_embaba_I; Tsaeda_embaba_II* and *Shashemanie_I* exhibited similar characteristics, yet they have different names. Most of the cultivars are given names by farmers based on where they were first introduced, for example *Shashemanie_I* while others are named based on their flower color, such as

Tsaeda_embaba (white flower colour). The current characterization thus confirms that they are either the same or closely related cultivars that share the same background. Previously, (Tairo *et al*., 2008) reported from their study that diverse system of sweet potato naming in Tanzania caused mixed up and duplication of cultivars as the same cultivars may be given different names in different localities.

At about 93% similarity, two more cultivars (*Shashemanie_II and Keyh_embaba_II*) joined group I. Yet at 92% similarity level, another two more (*Keyh_embaba_I* and *Keyh_embaba_III)* had joined the group. The later cultivars, although they share the same name as given by the farmers, have distinct variation from the other *Keyh_embaba*. Both produce red flower colour thus locally called (K*eyh embaba*). They were collected from different locations but because of some similarities they were clustered in one group. Further study is required to actually declare that they share a similar genetic background or not.

Group II had a number of sub classes. *Banba, Baren, Orla* and *Slaney* (obtained from NARI) together with *Safira, Zafira_I* and *Zafira_II* collected from farmers clustered together at >94% similarity level. The first four were imported from Ireland by NARI for research purposes and hence they are expected to cluster together. However, it infers that they have some genetic similarity with *Safira/Zafira* groups. It's not known if they share some genetic background. On the other hand cultivars *Round_Sudan, Grandinaine* and *Oval_Sudan* were grouped together. These materials were imported from a neighboring country, the Sudan, by individuals. The clustering analysis showed that there is some similarity (>93%) between them. There is a probability that they share some background based on this preliminary result.

The locally known cultivar *Carneshim* clustered separately from other cultivars grown in the same region such as *Yeha, Keyh embaba_I* and *Tsaeda embaba* (I & II), but is related to *Tsaeda embaba_III* from a different region. This indicates that it does not share any background with the rest of the materials growing in the same area (Sub-Zoba Serejeka) for many years. Another observation made during this cluster analysis is the name confusion between the cultivars called *Zafira* and *Safira*. The *Zafira* cultivar in Zoba Maekel was found to be different from the *Zafira* cultivar from Zoba Debub, indicating that although they share the same name they have no genetic similarity. On the other hand, the one called *Safira* showed a high degree of similarity (>94%) with *Zafira* collected from the same Zoba Debub explaining that they are either the same and/or share the same parental background. They were collected from the same region although with different names. While the *Keyh embaba_II* was found to be different from other *Keyh embaba* cultivars of 'I' and 'III' (Figure 4.3) which further indicates that although they share the same flower colour, they explained more variation in the rest of the descriptors. According to Fongod *et al*. (2012), if accessions differed in relation to various characteristics or descriptors, they will be classified in distinct groups in the cluster analyses revealing their differences. Moreover, Karuri *et al*. (2010) reported that genotypes sharing a common name were not necessarily identical although they clustered together.

The results of the cluster analysis conforms to the PCA bi-plot scattering obtained above where *Yeha, Tsaeda_embaba_II, Shahemanie_I, Tsaeda_embaba_I, Shashemani_II and Keyh_embaba_II* grouped together, yet *Keyh_embaba_I* and *Keyh_embaba_III* fell in the same quadrant while others scattered in second and third quadrant. Ahmadizadeh and Felenji (2011) obtained similar results and reported that principal component and cluster analysis yielded the same grouping of the accessions. According to Karuri *et al*. (2010) conclusion, a good breeding program can be initiated by the selection of cultivars from the PC1 and PC2 and/or group with maximum positive deviation from the total mean.

It was noted from the cluster analysis that there was no strong relationship between the clustering groups and geographic sources of cultivars. This can be ascribed to the free movement of seed tubers from one region to another within a country and the frequent illegal importation of potato materials from neighbouring countries. Similar results of no sharp relationship between the clustering pattern of accessions and their geographical sources were reported by Lohani *et al*. (2012) on potato and Karuri *et al*. (2010) on sweet potato.

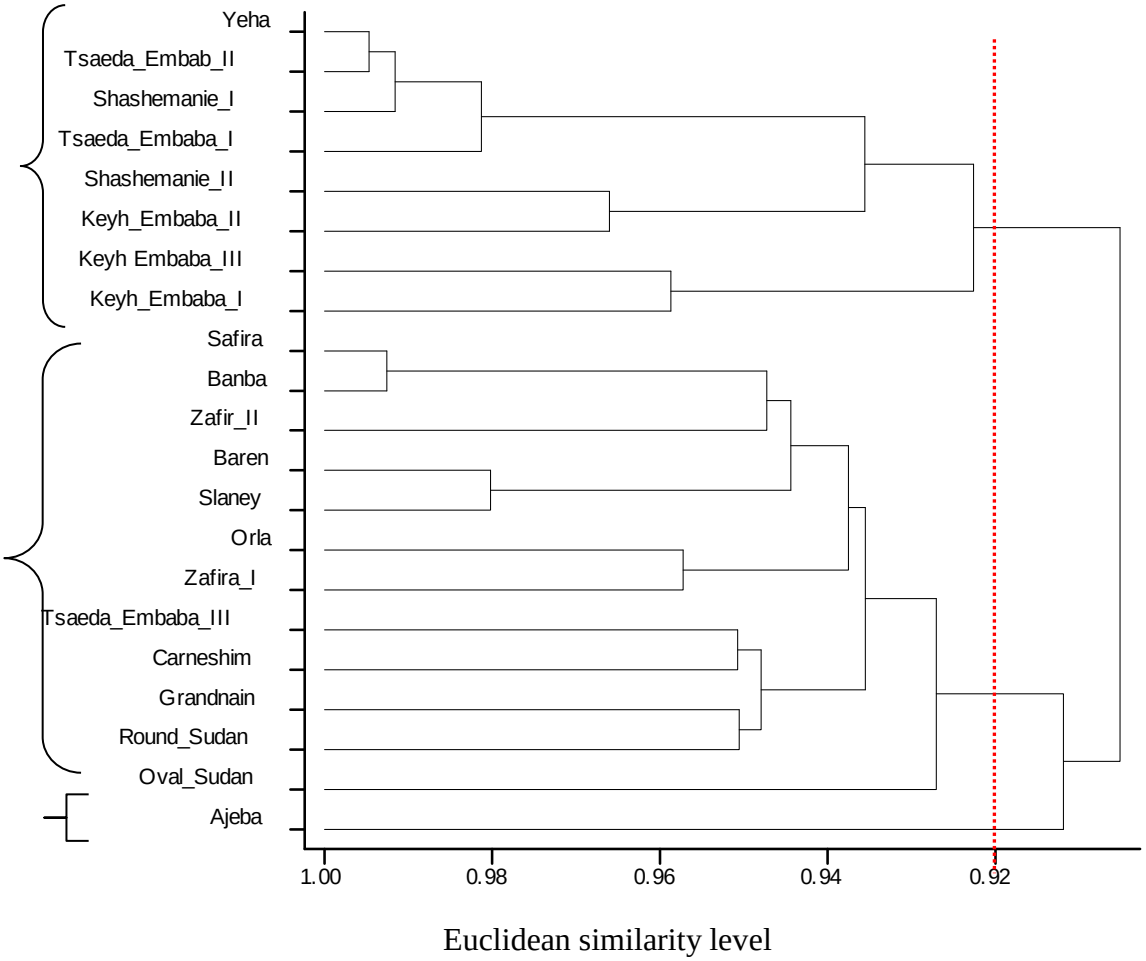


Figure 4.3: Dendrogram based on UPGMA clustering of the 21 cultivars studied.

4.3.6 Mean values of groups for the different traits

In order to record the value of each group in the cluster, mean deviation of each variable from the grand mean of the quantitative variables was calculated (Table 4.9). This comparison of values helped to identify positive traits contained by each group in comparison with the total mean and thus select parent lines for crop improvement. Accordingly, Group I; showed positive deviation to Flow DAP, No PS, PH, and tuber set. Most of the cultivars in this group performed well except the two cultivars (*Keyh_embaba I and III*). It should be noted that if these two inferior ones were removed from the group, the deviation becomes positive for most of the variables. Yet, Group II; deviated positively in all the variables except for Flow DAP, No PS, PH and tuber set. While Group III showed negative deviation except for Emer DAP, No PS and Tuber size. This is a cultivar preferred by most of the farmers owing to its early maturity (21 days earlier than the average) although lower yield as determined by weight. It is, thus, inferred that cultivars in Group I and II could be used as parental lines for breeding program depending on the required traits.

Table 4.9: Mean deviation of groups from the total mean for quantitative traits.

Group		Emer. DAP	Flow DAP	Maturity time	No. PS	PH	ST	T_set	T_size	T_wt
Total	Mean	33.7	55.7	108.3	2.8	21.8	8.4	9.0	39.4	0.43
	Difference	0	0	0	0	0	0	0	0	0
I	Mean	30.7	72.6	105.8	3.6	24.9	7.6	14.1	33.1	0.39
	Differences	-3.0	16.9	-2.5	1.8	3.1	-0.8	5.1	-6.3	-0.04
II	Mean	36.5	49.0	111.8	2.2	19.9	9.1	5.9	43.5	0.46
	Difference	2.8	-6.7	3.5	-0.6	-1.9	0.7	-3.1	4.1	0.03
III	Mean	23.5	0	87.0	3.1	19.1	6.7	5.3	41.9	0.35
	Difference	-10.2	-55.7	-21.3	0.3	-2.7	-1.7	-3.7	2.5	-0.08

4.4 Conclusion

The study of characterization of potato using morphological traits in this study is the first of its kind in Eritrea. Plant characterization is of paramount importance before going for any breeding program and/or plant genetic resources conservation purposes. Moreover, it is a good means of identifying duplicate materials to avoid mix-up.

The assessment revealed that there was a wide genetic variation among the potato cultivars studied based on their morphological characteristics. The findings support to reject the null hypothesis. Cluster analysis generated three groups at 92% similarity level with a number of sub clusters. The clustering helped to identify cultivars that share the same characteristics and/or that are closely related and *vice versa*. The clustering further discovered that cultivars with common name based on their flower colour may not necessarily contain the same genetic composition. It was observed that some cultivars with different given names were similar sharing more than 99% Euclidean similarity (eg. *Yeha* and *Tsaeda embaba*_II). Likewise materials collected from the same region were not necessarily similar. Mean deviation of variables for each group from the total mean indicated that Group II followed by Group I showed maximum deviation in most of the recorded yield related traits. These groups can, thus, be recommended for use as parental lines for a breeding program in Eritrea.

CHAPTER FIVE

GENETIC DIVERSITY ASSESSMENT OF POTATO (*SOLANUM TUBEROSUM* L.) CULTIVARS GROWN IN ERITREA USING SSR MARKERS

Abstract

Sixty three potato cultivars from Eritrea (51 farmers' and 12 imported) and 30 check varieties (18 from Kenya and 12 from Rwanda) were characterized using 12 simple sequence repeat (SSR) markers. The study was designed to assess the genetic diversity and varietal distinctness among the different samples. In total 91 alleles ranging between 2 (STM1053) to 13 (STM0031) alleles per marker were scored. About 97.8 of the alleles were highly polymorphic with an average PIC value of 0.87 (0.51-0.98). Samples from Eritrea showed the highest genetic diversity as explained by the diversity index (h). The principal coordinate analysis (PCoA) revealed that the local farmers' Eritrean cultivars were different from the Kenyan, Rwandese and the imported varieties. Genetic distance analysis generated three clusters correlating with the PCoA findings. Cluster I consisted of 45 samples with 6 sub-clusters; Cluster II consisted of 29 samples with a majority (26) from Eritrea while cluster III consisted of 19 samples. Potato cultivars from Eritrea appeared to cluster separately from the other samples, which reflect a contribution from the Tuberosum germplasm prominent in temperate regions. Most of the Eritrean samples in cluster I are farmers' cultivars with intermediate maturity, good performance and better tuber quality characteristics. Cluster II contains varieties from Eritrea characterized by late emergence and late maturity. The Kenyan and Rwandese grouped mainly in Cluster III. In summary the farmers' cultivars are distinct from the Kenyan and Rwandese materials and represent more genetic diversity than the varieties imported into Eritrea. This finding is of interest to national breeding program to use the farmer's materials as source of genetic variation for traits of interest.

5.1 Introduction

Potato crop plays a significant role in human nutrition worldwide, and more than 320 million tons of potato tubers are produced annually on 20 million hectares of land (Poczai *et al*., 2010). Being a major staple food crop in Eastern African countries, potato is highly rated among the choice crops for food security in the region (Kyamanywa & Kashaija, 2011).

According to Lutaladio *et al*. (2009) potato is rated as a crop with a high genetic diversity. The native potatoes of Chile, for instance, are characterized by a rich variety of forms, sizes, colours and phenological characteristics (Solis *et al*., 2007). Moreover, potato farmers in the Andes region grow approximately 4500 different native potato varieties or land races (Pamela, 2007). These varieties contain a wealth of valuable traits such as resistance to insect pests, diseases, rich nutritional value, taste and adaptation to extreme climatic conditions (Lutaladio *et al*., 2009). Similarly, Kandemir, Yilmaz, Karan, & Borazan (2010) have reported that landrace cultivars are significant sources of genetic variation, but need to be characterized. However, quite often the farmers lose these varieties due to factors including traditional farming practices, social unrest, natural calamities and severe pest attack (Lutaladio *et al*., 2009).

In Eritrea unknown types and numbers of potato cultivars are grown. The crop is among the most widely grown root crops. As the majority of the population (>70 %) rely on subsistence agriculture (NEPAD & FAO, 2005), its contribution is significant. The crop is generally believed to have been introduced into Africa around the turn of the 20th century (FAOSTAT, 2008). It is also assumed that the Italian colonizers introduced the crop to Eritrea around the same time. During the long tradition of potato cultivation in Eritrea, farmers adopted a number of cultivars. A farmers' cultivar can be defined as a potato cultivar produced by farmers under a local name with no known origin. Although farmers now grow recently introduced varieties from Europe, they still recognize the important values of farmers' cultivars such as good resistance to various stresses and

market value, but these cultivars are unfortunately low yielding (Biniam, Githiri, Tadesse, & Kasili., 2014). The farmers' cultivars and imported potato varieties have not been characterized genetically in Eritrea, which would help to understand their genetic diversity and distinctness. This knowledge is important for better orient potato breeding and germplasm conservation (Liao & Guo, 2014). For a long time, breeding was largely done based on morphological descriptors Yada *et al*. (2010) but with the new molecular technologies in breeding programs more diverse genetic resources, including those bearing known alleles of interests can be utilized (Nováková *et al*., 2010). Being an outcrossing and autotetraploid genome, cultivated potato is difficult candidate for genetic studies. Despite that, continuous genetic diversity assessment among potato species is important, as the flow of new genetic material into the gene pool of cultivated potato is continuous (Carputo, Alioto, Aversano, Garramone, & Miraglia, 2013).

Molecular markers are useful tools for germplasm management and for addressing genetic identity, duplication and genetic variation (Sajib *et al*., 2012; Tiwari *et al*., 2013). To increase the efficiency of genetic diversity characterization, molecular markers are particularly attractive (Carputo *et al*., 2013). The techniques based on molecular profiling provide reliable approaches to variety identification that complements morphological means. To that effect, molecular markers are widely used to distinguish genetic variation within and among cultivars (Kubik *et al*., 2009; Moissan-Thiery *et al*., 2005). Several molecular approaches such as AFLP (Ghislain *et al*., 2006) and RAPD (Rocha *et al*., 2010) have been applied for potato genetic diagnosis. Each of these tools have their own pros and cons (Nováková *et al*., 2010). Microsatellite markers also known as Simple Sequence Repeats (SSR), are particularly helpful since they are highly polymorphic co-dominant markers (Barandalla *et al*., 2006; Chimote *et al*., 2007; de Galarreta *et al*., 2007; Ghislain *et al*., 2009; Tiwari *et al*., 2013), have low operational costs, and show high quality and highly reproducible bands (Favoretto *et al*., 2011; Spooner *et al*., 2007). The SSR markers are widely used for diversity studies, as well as for parentage analysis and Quantitative Trait Loci (QTL)

mapping. Moreover, they have the ability to determine the ploidy level, as well as the high heterozygosity of the tetraploid (Muthoni *et al*., 2014). They have been used extensively in potato and other crops for various breeding and diversity studies (Kandemir *et al*., 2010; Ghislain *et al*., 2009). The high level of polymorphism and heterozygosity explained by microsatellite markers in potato suggests that they may be useful tools in addressing genetic differences between closely related taxa (Raker & Spooner, 2002). More importantly, in developing countries, where trained human resources lack, SSRs are a suitable option for use in breeding programs that apply molecular techniques (Ghislain *et al*., 2004).

Ghislain *et al*. (2009) identified more than 150 potato SSR markers distributed throughout the whole genome. The authors also developed a molecular identification kit, known as Potato Genome Identification (PGI) kit, consisting of 24 highly powerful markers representing two loci per chromosome. The kit provides high Polymorphic Information Content (PIC) value, which is locus-specific with a high quality of amplicons (Ghislain *et al*., 2009). Moreover, Ghislain *et al*. (2004) recommended 18 highly informative and user friendly SSRs markers after screening 156 SSRs for their characterization power in potato accessions. According to Berg & Hamrick (1997) a sample size of 30-50 accessions using 10-20 markers can successfully characterize the genetic diversity in the population. The authors opined that adding more individuals or loci will not appreciably change the standard statistics of genetic variability. Several other studies demonstrated that five or six pairs of SSR markers were sufficient to distinguish many potato cultivars (Zhuk, Veinberga, Skrabule, & Rungis, 2008).

The aim of this study was to assess genetic diversity and relatedness among farmers' potato and introduced varieties from Eritrea and compare it to other potato germplasm from Kenya and Rwanda using 12 SSR markers.

5.2 Materials and Methods

5.2.1 Plant material and markers

A total of 63 potato cultivars from Eritrea were used in the study in addition 30 varieties obtained from International Potato Center (CIP, Sub-Saharan regional office, Nairobi Kenya) comprising 18 from Kenya and 12 from Rwanda were used as checks. Cultivars from Eritrea were grown in pots in the greenhouse located at National Agricultural Research Institute (NARI), Halhale, Eritrea, whereas the materials from CIP were grown in the greenhouse located at the Biosciences eastern and central Africa (BecA)–ILRI hub, Nairobi, Kenya. Fresh leaves of two weeks old were collected from each cultivars.

5.2.2 DNA extraction

Extraction of DNA was done from fresh tender leaves with a combination of the modified Cetyl-Trimethyl Ammonium Bromide (CTAB) (Semagn, 2014) and the QIAGEN DNeasy mini Kit methods. The quantity and quality of the extracted DNA was determined using the Nanodrop® 2000C spectrophotometer and agarose (0.8%) gel electrophoresis stained with GelRedTM (Biotium USA) (25 µl/L). Genomic DNA was normalized to a final concentration of 20 ng/µl after which it was subjected to PCR amplification using a set of 12 fluorescently labelled SSR markers (Table 5.1) as reported by (Ghislain *et al*., 2009).

5.2.3 PCR conditions

The extracted genomic DNA was subjected to PCR amplification using the 12 SSR markers as per the following conditions. AccuPower® PCR pre-mix without dye but containing DNA polymerase dNTPs Tris-HCL KCl and $MgCl_2$ was used. A reaction mix of 10 µL volume containing 0.84 µL forward primer fluorescently labelled at the 5' end with either 0.4 µL of dye- 6-FAM, VIC, PET or NED, 1µL of reverse primer, 1µL of template DNA and topped up with sterile distilled water. DNA was amplified using the Techne® TC-PLUS thermal cycler conditioned to the following setting:

Denaturation at 94 ^{o}C for 5 min; 35 cycles consisting of a denaturation at 94 ^{o}C for 30 sec, annealing (55-60 ^{o}C depending on the markers) for 1 min, and extension at 72 ^{o}C for 1 min; and finally *final extension* at 72 ^{o}C for 20 min. Quality of the amplified PCR products was determined using 2% agarose gel electrophoresis for 45 min at 70 V and observed using Syngene bio imaging gel documentation (Figure 5.1 A). High quality amplified PCR products were pooled based on the florescent dye used and analysed by capillary electrophoresis on ABI PRISM 3730 (Applied Biosciences).

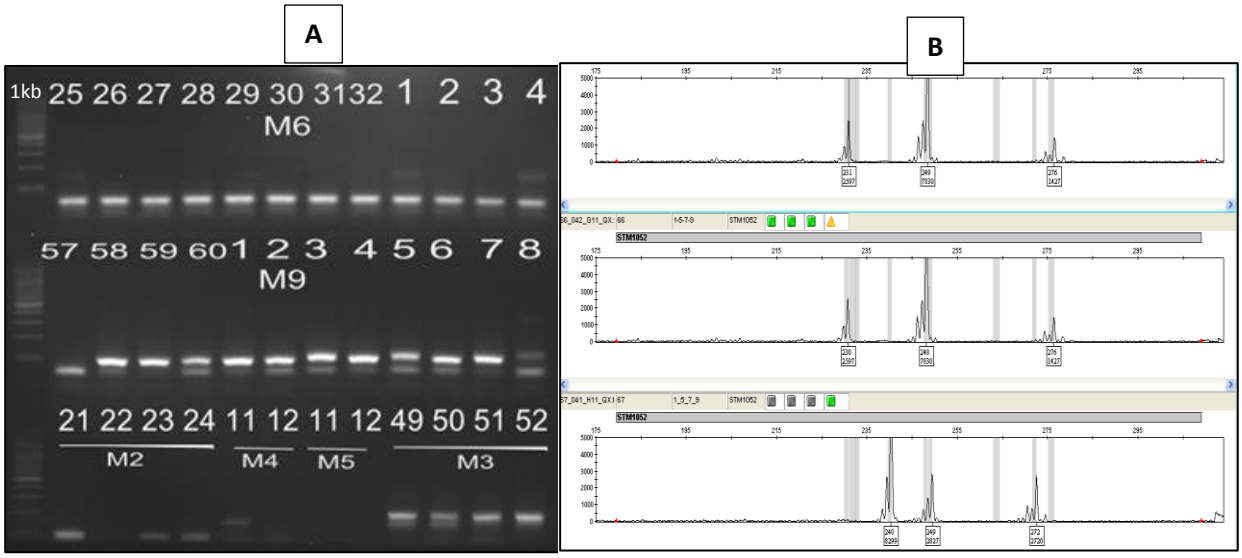


Figure 5.1: Gel reading of DNA PCR products "A" and allele scoring "B".

5.2.4 Co-loading conditions

Amplified PCR products of the 4 different markers tailed with fluorescent dye were pooled together. The co-loading was based on the florescent dye fragment size and dye fluorescence strength with either 1 or 1.5 µL PCR product (depending on the strength of the dye) from each of the 4 markers was mixed together and centrifuged. After wards, 1.5 µL of the mixture was added to a new tube containing 9 µL of Hi-Di formamide (Applied Biosystems) and GeneScan Liz 500 size standard (Applied Biosystems). After centrifuging, samples were heated at 94 ^{o}C for 5 min and fast cooled on ice.

5.2.5 Data Analysis

Raw data was generated on the ABI PRISM 3730 (Applied Biosciences) using capillary electrophoresis genetic analyser. Samples were scored using the GeneMapper Version 4.1 software (Applied Biosystems) to determine and score allele peak sizes (Figure 5.1 B). Alleles scored from the gene mapper were subjected to different downstream data analysis software such as AlleloBin (Prasanth, Chandar, Hoisington, & Jayashree, 2006), ALS binary (Bioinformatics Unit ICRISAT), GenAlex version 6.4 (Peakall & Smouse, 2012), DARwin 6.0 dissimilarity analysis software (Perrier, X., & Jacquemoud-collet, 2006) and Power-Marker version 3.25 (Liu & Muse, 2005). Polymorphic SSR bands for each individual were scored as single dose allele markers according to (Kubik *et al*., 2009) where data had to be converted to binary format as presence or absence.

AlleloBin was used to determine exact allele call size based on the motif size or repeat length provided. Quality index from the AlleloBin was interpreted as follows: 0.00–0.30: no inspection required; 0.31–0.40: binning likely good; 0.41–0.45: binning or sizing poor; > 0.45: binning and sizing unacceptable (Idury & Cardon, 1997). For further analysis these sizes had to be converted into binary (0/1) where 0 is absent and 1 is present, using the ALS binary software.

GenAlex was used to calculate genetic distances matrix among the samples, which further yielded the Principal Coordinate Analysis (PCoA). The binary data set option was used for all analyses in the GenAlex software. The PCoA helped to visualize the distribution of the materials across the 2D scatter plot graph coordinates thus understand their genetic relationships. Moreover, this software was used to calculate Analysis of Molecular Variance (AMOVA) to compute the differences of variance among the cultivars and percentage of polymorphism, the number of private alleles, and unbiased genetic identity, based on 999 permutations.

Table 5.1: Characteristics of the 12 SSR markers used in this study.

Locus	Motif	Forward	Reverse	Size (bp)	Dye	Annealing T (°C)	Chromosome Position
STG0016	$(AGA)_8$	AGCTGCTCAGCATCAAGAGA	ACCACCTCAGGCACTTCATC	137 - 174	PET	56	I
STM5114	$(ACC)_7$	AATGGCTCTCTCTGTATGCT	GCTGTCCCAACTATCTTTGA	297 - 325	VIC	55	II
STM1053	$(TA)_4$ $(ATC)_5$	TCTCCCCATCTTAATGTTTC	CAACACAGCATACAGATCATC	170 - 196	6-FAM	55	III
STI0012	$(ATT)_n$	GAAGCGACTTCCAAAATCAGA	AAAGGGAGGAATAGAAACCAAAA	183 - 234	NED	56	IV
STI0032	$(GGA)_n$	TGGGAAGAATCCTGAAATGG	TGCTCTACCAATTAACGGCA	127 - 148	PET	60	V
STI0004	$(AAG)_n$	GCTGCTAAACACTCAAGCAGAA	CAACTACAAGATTCCATCCACAG	83 - 126	PET	56	VI
STM0031	$(AC)_5$ ... $(AC)_3$	CATACGCACGCACGTACAC	TTCAACCTATCATTTTGTGAGTCG	168 - 211	NED	60	VII
STM1104	$(TCT)_5$	TGATTCTCTTGCCTACTGTAATCG	CAAAGTGGTGTGAAGCTGTGA	178 - 199	VIC	60	VIII
STM1052	$(AT)_{14}$ GT $(AT)_4$ $(GT)_6$	CAATTTCGTTTTTTCATGTGACAC	ATGGCGTAATTTGATTTAATACGTAA	214 - 263	NED	55	IX
STM1106	$(ATT)_{13}$	TCCAGCTGATTGGTTAGGTTG	ATGCGAATCTACTCGTCATGG	151 - 214	VIC	60	X
STM0037	$(TC)_5$ $(AC)_6$ AA $(AC)_7$	AATTTAACTTAGAAGATTAGTCTC	ATTTGGTTGGGTATGATA	87 - 133	6-FAM	55	XI
STI0030	$(ATT)_n$	TTGACCCTCCAACTATAGATTCTTC	TGACAACTTTAAAGCATATGTCAGC	94 - 137	6-FAM	56	XII

Cluster analysis and tree construction was conducted using DARwin 6.0, by estimating dissimilarity indices based on the binary data (simple allele matching). The genetic similarity matrix of the potato samples was calculated using the Jaccard coefficient, after which a dendrogram was generated using Unweighted Pair-Group Method using

Arithmetic Averages (UPGMA) based on the estimates of genetic similarity. Power-Marker version 3.25 was used to calculate Polymorphic Information Content (PIC) to estimate the power of the marker in explaining variation among the samples.

5.3 Results and Discussions

5.3.1 Allele profile

The analysis of the data using allelobin yielded a total of 91 amplified alleles, of which 33 alleles (36%) were rare (≤5%). The number of alleles per locus ranged from 2 (STM1053) to 13 (STM0031) with an average of 7.83 alleles per marker (Table 5.2). In previous similar studies a great variation of results were reported. Chimote *et al*. (2007) found a total of 123 amplified alleles in potato using 4 SSR markers with an average of 34 alleles per marker. Moreover, Rocha *et al*. (2010) reported a total of 136 polymorphic fragments amplified in potato using 20 primers with an average of 6.8 per primer. The average number of alleles amplified per locus in potato from Kenya ranged from 2 to 14 with an average of 6.67 (Muthoni *et al*., 2014). Similarly, Favoretto *et al*. (2011) found a total of 46 alleles amplified using 10 SSR markers. Yet, Carputo *et al*. (2013) reported a total of 46 alleles using 12 SSR markers with an average of 3.8 allele per locus in potato accessions; while Solano, Mathias, Esnault, & Brabant (2013) reported an average of 9.16 per locus where 64 alleles were amplified using 7 SSR markers. Recently, Muhinyuza *et al*. (2015) reported a total of 84 alleles amplified using 13 SSR markers. This high variation and high polymorphism level is ascribed to the ploidy nature of the crop, which is tetraploid, and the SSR markers used. Kandemir *et al*. (2010) reported that SSR markers are useful tools to differentiate potato cultivars. The 12 SSR markers used in the current study revealed high polymorphism level among the 93 potato cultivars. Gwandu *et al*. (2012) reported that only four SSR markers were able to distinguish between 161 sweet potato accessions used in Tanzania.

On average, 84% of the potato samples shared a common major allele at any given locus ranging from 46% (STM0031) to 100% (STM1053 and STI0030). Only two alleles namely STM1053_195 and STI0030_109 were found in all the cultivars (monomorphic), while the rest of the alleles were shown to be polymorphic, making an average of 97.8% polymorphism. Favoretto *et al*. (2011) reported 89.1% polymorphism in 38 potato accessions using 10 SSR markers. The quality index of the markers ranged from 0.089 (STM1053) to 0.5 (STM0032) with an average of 0.322. However, 91.6% of the markers showed quality index of less than 0.45 indicating that binning and scoring was acceptable.

There was moderately negative correlation of the motif size (SSR repeats length) with the allele number amplified (r = -0.31); with quality index (r = -0.45) and with PIC (r = -0.37). On the other hand, it was noted that there was moderate positive correlation of the allele number scored with quality index (r = 0.52) and with PIC value (0.58). Madhusudhana, *et al*. (2012) reported significant negative correlation of the repeat motif type with repeat number (r = -0.44); with allele number (r = -0.39) and with PIC values (r = -0.38). This is in contrast to the report by (Solano *et al*., 2013). Yet, Muthoni *et al*. (2014) and Muhinyuza *et al*. (2015) reported strong positive correlations between number of alleles (r = 0.77) and PIC (0.86), while Zhang *et al*. (2000) and (Sajib *et al*., 2012) reported no correlation between repeat number and polymorphism in sweet potato.

5.3.2 Polymorphism Information Content (PIC) value

The SSR markers had high PIC values, and thus were highly informative and polymorphic (Table 5.2). The table shows that the lowest PIC value was 0.51 (STM1053) with highest 0.98 (STM0037) and mean 0.87. The PIC value measures the discriminatory power of the markers among the cultivars. Moreover, according to Muhinyuza *et al*. (2015), PIC effectively demonstrates the power of SSR markers in determining genetic variation among potato cultivars. The value reported by several studies in potato varied depending on the primers used and sample tested. The PIC value

reported by several studies in potato ranged from 0.00 to 0.94 depending on the markers used and accessions tested (D'hoop *et al*. 2010; Favoretto *et al*. 2011; Ghislain *et al*. 2006; Liao & Guo 2014; Muhinyuza *et al*. 2015; Muthoni *et al*. 2014; Rocha *et al*. 2010; Solano *et al*. 2013). The mean PIC value of the current study was high (0.87) as the polymorphism level is usually high for potato cultivars Ghislain *et al*. (2006). This could be attributed to the tetraploid nature of the crop as each locus contains between one and four different alleles (Muthoni *et al*. 2014). According to Solano *et al*. (2013), high PIC values is an indication of wide genetic diversity among the accessions.

Table 5.2: Allele analysis summary of the SSR markers.

Marker	Total No of Allele	Gene Diver	PIC	Repeat length	Quality Index	Abundant Allele	Rare Allele (<=5%)
STG0016	09	0.94	0.93	3	0.166	160 (69%)	145 148 166 184
STM5114	06	0.89	0.88	3	0.255	321 (79%)	318 324
STM1053	02	0.58	0.51	3	0.089	195 (100%)	None
STI0012	07	0.91	0.91	3	0.152	195 (62%)	213
STI0032	05	0.95	0.95	3	0.501	135 (73%)	144
STI0004	10	0.87	0.86	3	0.386	103 (73%)	91 100 115 118 124 130
STM0031	13	0.93	0.93	2	0.444	164 (46%)	150 184 190 230
STM1104	06	0.87	0.86	3	0.413	194 (76%)	191 200 203 206
STM1052	07	0.95	0.94	2	0.456	232 (54%)	None
STM1106	06	0.81	0.80	3	0.130	181 (76%)	184 217
STM0037	08	0.98	0.98	2	0.335	94 (98%)	104 106
STI0030	12	0.94	0.94	3	0.344	109 (100%)	85 91 94 100 106 121 136
Mean	**7.83**	**0.89**	**0.87**		**0.322**		

5.3.3 Potato germplasm structure

Mean number of observed and expected heterozygosity was calculated using the data set of 93 samples and 12 SSR markers to estimate the structure of the various

populations (Table 5.3). Determining the expected heterozygosity of populations is becoming an increasingly important aspect of genetic studies. Samples from Eritrea showed highest genetic diversity as explained by the observed heterozygosity (h). The observed gene diversity ranged between 0.19 (Kenya and Rwanda) to 0.21 (Maekel). The mean expected heterozygosity for the cultivars was 0.21; indicating that 21% of the studied genetic individuals are expected to be heterozygous at a given locus. It was noted that there was a slight increase in the value of Nei's unbiased estimate of expected gene diversity as compared to the observed across all markers in the population. This is attributed to the basic characteristic of inbreeding effect of crops (Kitavi *et al*., 2014). Reduced level of observed heterozygosity (increased homozygosity) is an indication of inbreeding effect, a common phenomenon in crops like potato owing to their vegetative propagation method.

Table 5.3: Population estimation based on number of different alleles, polymorphism (%), and diversity level.

Population	N	Na (SE)*	%P	uh (SE)*	h (SE)*
Zoba Debub	27	1.33 (0.10)	65.9	0.22 (0.02)	0.21 (0.02)
Zoba Maekel	24	1.45 (0.09)	72.5	0.21 (0.02)	0.20 (0.02)
NARI	12	1.12 (0.11)	56.0	0.22 (0.02)	0.20 (0.02)
Kenya	18	1.34 (0.10)	65.9	0.20 (0.02)	0.19 (0.02)
Rwanda	12	0.29 (0.10)	62.6	0.21 (0.02)	0.19 (0.02)
Mean		**1.31**	**64.6**	**0.21**	**0.20**
SE		**0.05**	**2.7**	**0.01**	**0.01**

Note: N = population number; Na = number of different alleles; %P= polymorphic percentage; uh= Unbiased expected heterozygosity; h= observed heterozygosity. *= standard error

5.3.4 Principal Coordinate analysis (PCoA)

Principal coordinate analysis (PCoA) was performed to estimate the genetic distance between each group of the cultivars using GenAlex software. The preliminary analysis of PCoA indicated that the first 3 axes explained a cumulative of 27.9% variation

among the population (Table 5.4). The PCoA analysis further indicated that the overall samples could be grouped into three major clusters (Figure 5.2). The majority of the Kenyan, NARI alongside a few Rwandese materials were grouped together in the center. The PCoA analysis showed that there was no distinct relationship between the samples and their geographic origins within the Eritrean materials. They were widely scattered in all four coordinates. This could be attributed to the free movement of samples between Zobas by farmers and thus the same cultivars were available everywhere. This is in contrast with Solano *et al*. (2013), who reported that cultivars were clustered in accordance to their geographical origin. The latter may illustrate the difference in how farmers obtain their seed, which in Chile is largely through specialized seed producers.

Table 5.4: Percentage of variation explained by the first 3 axes.

Coordinates	**Axis**		
	1	**2**	**3**
%	13.4	7.5	7.0
Cum %	13.4	20.9	27.9

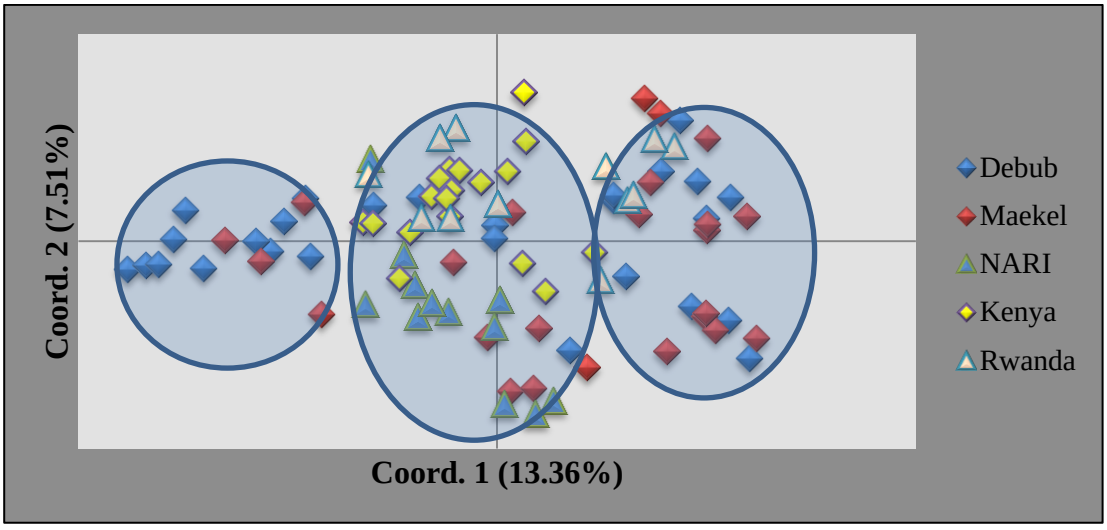


Figure 5.2: Principal coordinates analysis of the 3 populations.

A separate analysis of the Eritrean materials indicated that they were scattered all over the coordinates with the exception of materials imported from Ireland by NARI which concentrated in the centre (Figure 5.3). This once more is ascribed to the free movement of materials with in the country.

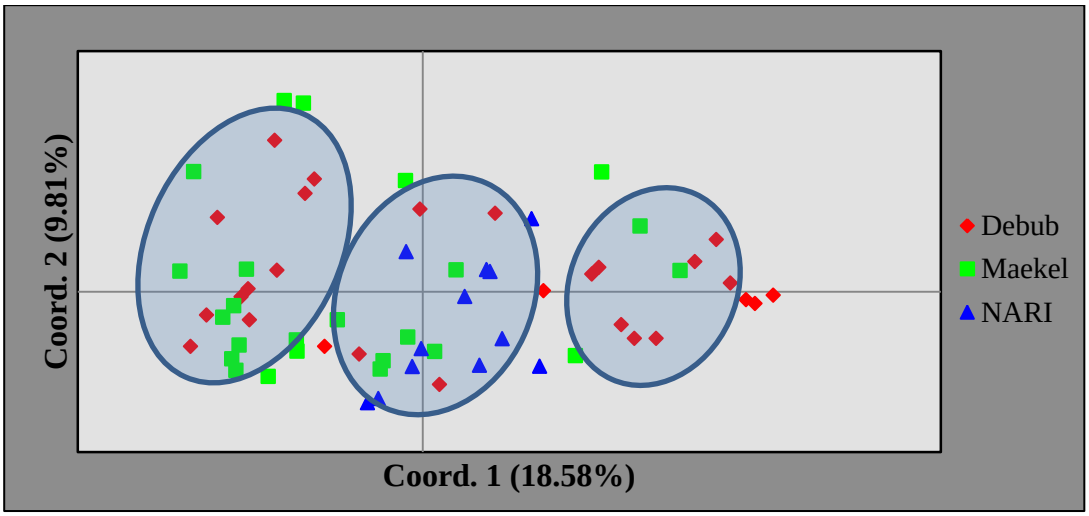


Figure 5.3: Principal coordinates analysis of the Eritrean potato samples.

Another separate PCoA test at population level explained a total of 92.43% variation by the first three axes (Table 5.5). The analysis further differentiated the populations distinctly where materials from Kenya and Rwanda clustered together and were explained mainly by the positive loading of coordinate 1. On the other hand, materials from Zoba Maekel and Zoba Debub regions clustered together and were explained by positive loading of coordinate 2, while NARI materials grouped separately with a positive loading from both coordinates 1 and 2 (Figure 5.4).

Table 5.5: Percentage of variation explained by the first 3 axes at population level

Axis	1	2	3
%	49.30	28.66	14.47
Cum %	49.30	77.96	92.43

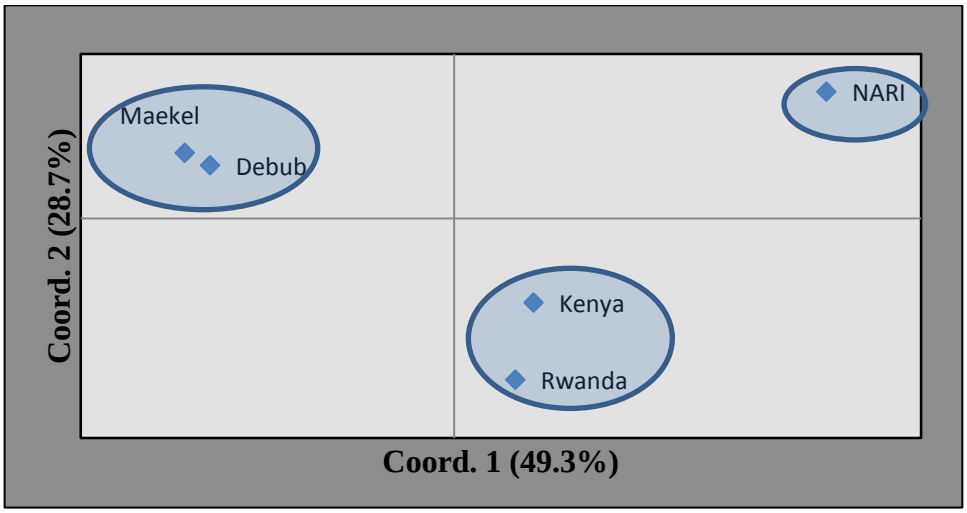


Figure 5.4: Principal coordinate analysis of the populations based on genetic distance matrix (NeiP).

5.3.5 Analysis of Molecular Variance (AMOVA)

Analysis of molecular variance (AMOVA) was done to assess and quantify the diversity level and the genetic relationship among the 93 samples. Preliminary AMOVA showed that there was a significant variation at ρ=0.001 among populations and within population. About 92% of the variation was recorded within populations while the remaining 8% was among populations (Table 5.6). Similarly high variation (93%) within the Indian Andigena potato core collection was reported by Tiwari *et al*. (2013). Previously, about 97% variation within groups was reported by Gwandu *et al*. (2012) on sweet potato virus disease resistance. According to Hamrick and Godt (1997),

outcrossing crops like maize, including potato, have most of the variation observed within populations, rather than between.

Table 5.6: Analysis of molecular variance (AMOVA).

Source	Df	SS	MS	Est. Var.	%	ρ-value
Among Populations	4	108.438	27.109	0.965	8%	0.001
Within Population	88	848.380	9.641	9.641	92%	0.001
Total	92	956.817		10.606	100%	

Genetic diversity among the population of potato samples was determined using the unbiased Nei's genetic distance analysis. The genetic distance matrix index among population ranged from 0.011 and 0.048 (Table 5.7). The Nei pairwise population matrix explained the genetic relationship between the populations. The results indicated that there was relatively close relationship between the two Eritrean samples Zoba Debub and Zoba Maekel as well as between the Kenyan and Rwandese populations. This conclusion was further supported by the previous PCoA analysis. The highest variation was noted between NARI and Rwandese samples (0.048). The low values of the Nei genetic distance matrix indicate that, although there is some noticeable variation among the populations in general, potato cultivars are very closely related and share a high degree of genetic similarity. Recently, Liao and Guo (2014) reported that among 85 potato cultivars from Yunnan, China, studied using 24 SSR markers, there was relatively low genetic diversity as explained by the genetic similarity matrix. Earlier, it was also reported by Gebhardt *et al*. (2004) that high genetic similarity was noted as a result of narrow genetic base in European cultivated potatoes. Relatively narrow genetic basis of the cultivated potato make *Solanum* species unique materials for breeding (Carputo *et al*., 2013).

Table 5.7: Pairwise population matrix of Nei unbiased genetic distance.

	Zoba Debub	Zoba Maekel	NARI	Kenya	Rwanda
Zoba Debub	0.000				
Zoba Maekel	0.011	0.000			
NARI	0.033	0.024	0.000		
Kenya	0.032	0.036	0.036	0.000	
Rwanda	0.032	0.028	0.048	0.018	0.000

5.3.6 Cluster analysis

The UPGMA analysis generated a dendrogram based on the dissimilarity matrix of the alleles scored from the samples. Bootstrap values ≥ 60% from 100 replications are indicated above the nodes (Figure 5.5). The analysis generated a tree corresponding to the PCoA in many parts. The populations were grouped into three main clusters. The Kenyan and Rwandese populations were combined together. The biggest group was Cluster I consisting of 45 samples with 6 sub clusters (a, b, c, d, e, and f). Sub cluster "a" contained of 3 samples from Eritrea; sub cluster "b" had 8 from Eritrea; and sub cluster "c" contained 3 from Kenya and 1 from Rwanda. Sub cluster "d" consisted of 4 samples from Rwanda; while sub cluster "e" and "f" consisted of 15 from Eritrea and 10 from Eritrea and one from Rwanda, respectively. Cluster II consisted of 29 samples with a majority (26) from Eritrea; 2 from Kenya; and 1 from Rwanda. Cluster III consisted of 19 samples, 13 from Kenya; 5 from Rwanda; and 1 from Eritrea. Cluster I was mainly dominated by the Eritrean farmers' cultivars with distinct characteristics from the newly introduced varieties. The latter are mainly grouped in Cluster II. Whereas the majority of Kenyan and half of the Rwandese were found in cluster III. The Eritrean populations, even though a distinct variation was noted within each other, were found to be different

from the Kenyan and Rwandese. This was also supported by the PCoA analysis and Nei unbiased genetic distance matrix.

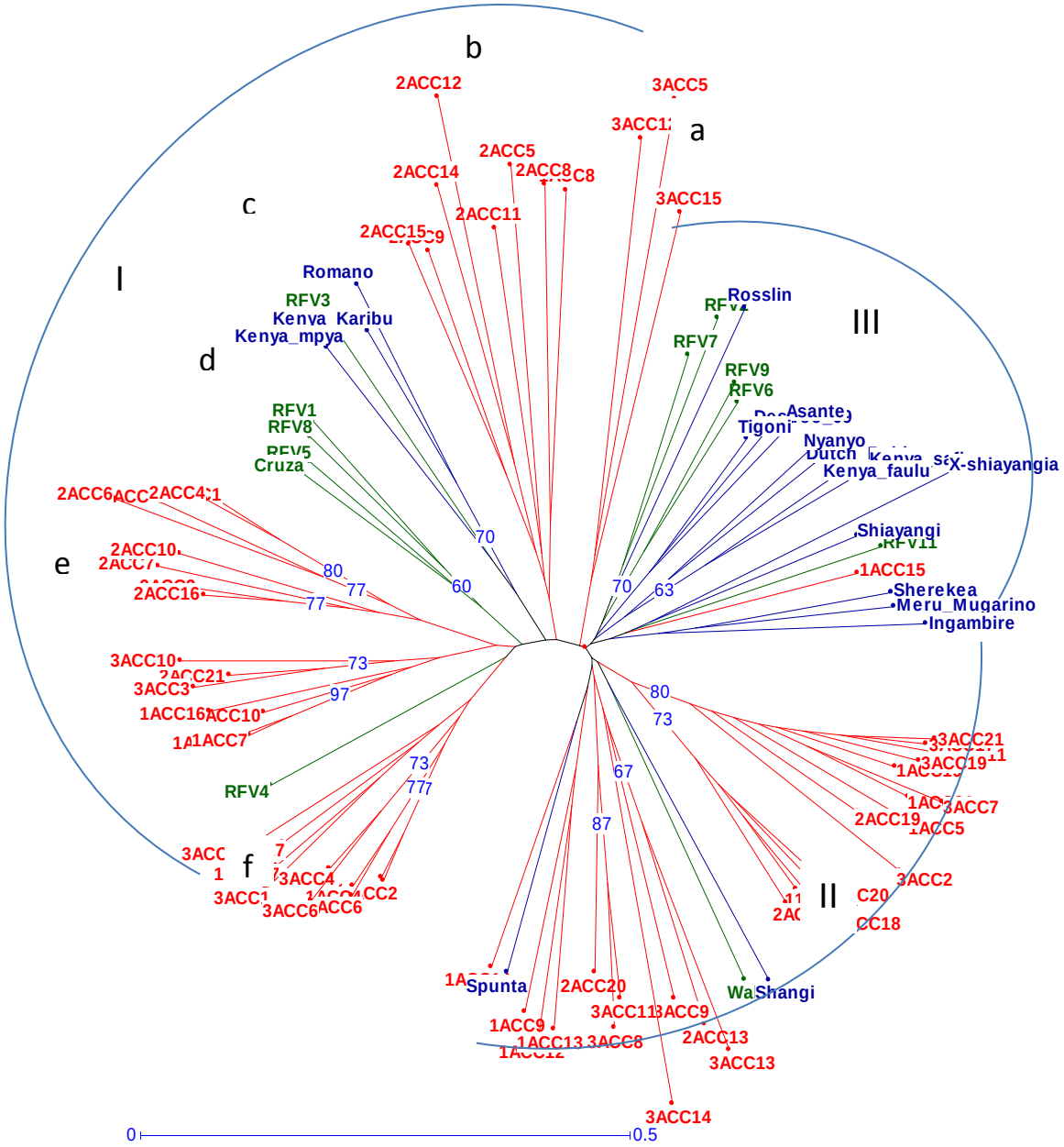


Figure 5.5: Unrooted UPGMA dendrogram cluster analysis of the 3 populations.

5.4 Conclusion

Genetic diversity assessment is essential for identifying potential parents for plant breeding programmes as well as conservation of useful germplasm. The 12 set of SSR markers able to characterize the potato cultivars from Eritrea, Kenya and Rwanda. The samples from Eritrea showed some degree of genetic distinctness from the Kenyan and Rwandese samples. Eritrean farmers' cultivars were markedly more genetically diverse than the newly introduced varieties. The study revealed the genetic diversity among the studied cultivars where by rejecting the null hypothesis. The taxonomic origin of the Eritrean potato germplasm is not known, but the results from this study indicate that it could be of Tuberosum origin from European germplasm and not an Andigenum origin released in the tropical zone (Kenya and Rwanda) from CIP breeding material. It could be inferred that the Eritrean potato farmers' cultivars were more diverse than the newly introduced varieties and could therefore be exploited for breeding purposes.

CHAPTER SIX

NUTRITIONAL ANALYSIS OF FARMERS' POTATO (*SOLANUM TUBEROSUM* L.) CULTIVARS GROWN IN ERITREA

Abstract

Potato is a cool season crop grown for domestic consumption, in Eritrea. The nutritional composition of the cultivars grown in the country has not been studied. The aim of this study was to determine the nutritional composition of fresh and dry samples of 15 potato cultivars (boiled or raw) from Eritrea. The fresh samples were analyzed for total soluble solids (TSS), specific gravity (SG), moisture content (MCF) and dry matter content (DMC) while the dry samples were analyzed for protein, Phosphorous (P), ash and dry moisture (MCD) levels. The study was conducted in triplicates for each sample (raw and boiled). There were highly significant differences ($\rho<0.001$) among samples for TSS, SG, DMC, protein, ash, MCD and P. Boiling significantly ($\rho<0.001$) reduced the levels of all the traits studied. The results further indicated that there was positive correlation between TSS and P; yield with SG and MCD; protein with ash and TSS. It was noted that about 47%, 60% and 40% of the studied samples recorded values that were higher than the mean average for crude protein, DMC and P, respectively. It can be concluded from the current study that the nutritional content varies considerably among the potato cultivars. Moreover, boiling significantly reduced the nutritional content of potato. The identified cultivars with higher nutritional values for respective traits could be used in breeding programs.

6.1 Introduction

Potato is one of the most important crops, significantly contributing to the world food nutritive value (Gumul *et al*., 2011; Ikanone & Oyekan, 2014). It is uniquely positioned to be a valuable source of dietary vitamins, minerals, and phytonutrients because of its per capita consumption (Prokop & Albert, 2008; Navarre, Goyer, & Shakya, 2009). Its

nutritional contribution in developing countries is significant high (Badoni & Chauhan, 2009). Potato tubers are rich in protein, calcium, potassium, and Vitamin C, and have good amino acid balance (Elfaki & Abbsher, 2010; Ikanone & Oyekan, 2014; López *et al*., 2013; Mehdi, Saleem, Rai, Mir, & Rai, 2008). The tubers can be eaten boiled, roasted, baked or fried and are processed into a wide range of products such as fries, chips, baked, cooked (Kroll, 1997; Stark *et al*., 2009). The crop's contribution to food and nutrition security has been documented in the rural Peruvian region (Rose *et al*., 2009) and Kenya (Abong *et al*., 2009). Owing to this fact, the International Potato Center (CIP) has for a long time been engaged in conducting research to improve the livelihood of potato farmers by increasing yields for enhanced food security and nutritional supply.

Abong *et al*. (2009) reported that new variety development in Kenya does not consider the nutritional value and suitability for domestic and industrial use. This is particularly essential as the nutritional content of potato vary depending on genetic composition and growing condition (Abong *et al*., 2009; Alting *et al*., 2011; Bartova *et al*., 2009) as well as on the cooking and consumption methods (Elfaki & Abbsher, 2010). The various cooking and processing methods make the tubers palatable but also have adverse effects on the nutritional contents (Ikanone & Oyekan, 2014). Hence, not all varieties are good for all end uses as each potato variety has unique tuber chemical composition (Chemeda, Bultosa, & Dechassa, 2014). The choice of variety is, thus, the most critical decision with respect to matching tuber quality with intended market (Stark *et al*., 2009).

Potato (*Solanum tuberosum* L.) has been cultivated for a long time in Eritrea and it is the second most important staple crop after sorghum. Its mode of consumption varies from place to place, but cooking followed by boiling are the most common. However, no analysis on its nutritional content has been done so far for the cultivars grown in the country. Hence, objective of this study was to characterize fifteen potato cultivars for their nutritional composition. By the end of this study useful information on the

nutritional content of the cultivars will be generated which will undoubtedly be useful for breeding programs and policy makers.

6.2 Materials and Methods

6.2.1 Plant materials

A total of 15 potato cultivars out of the original 21 cultivars were used based on their field performance and consumers preferences (Table 6.1). Potato seed tubers of each cultivar were planted in three replications in Hamelmalo Agricultural College (HAC), Eritrea in early 2015. Freshly harvested samples of each cultivar were analyzed for total soluble solids (TSS), specific gravity (SG), fresh moisture content (MCF) and dry matter content (DMC). The remaining samples of each cultivar were further divided into two parts for analysis in raw and boiled form. The boiling treatment consisted of bringing the water to boil followed by 15 min boiling. Each part was then sliced and sun dried for two days before they were transported to Kenya for further nutritional analysis in the Biosciences eastern and central Africa- International Livestock Research Institute (BecA-ILRI-HUB) laboratory, Kenya. The dried sample of each treatment and replication was finely grounded in to powder using an electric grinder and the flour was sealed in plastic bags and stored in a refrigerator at 4ºC according to Porras *et al*. (2014) until further chemical analysis for (crude protein, vitamin C, ß-carotene, ash, dry moisture content (MCD) and P).

6.2.1.1 Fresh samples analysis

a) Total Soluble Solid (TSS): the TSS was determined for each sample and treatment using a digital refractometer and expressed as ºBrix.

b) Specific gravity (SG): Samples were first weighed in air and then the same units were re-weighed suspended in water according to (CIP, 2006b). Specific gravity was then calculated using the formula:

$$\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Weight in air} - \text{Weight in water}}$$

c) Fresh moisture content (MCF%): Tuber moisture content was determined using an oven and balance method as described by Kabira & Lemaga (2003) and CIP (2006b).
d) Dry matter content (DMC%): The dry matter content was determined using an oven and balance method as described by Kabira & Lemaga (2003) and CIP (2006b).

$$Dry\ mater(\%) = \frac{\text{dry weight}}{\text{fresh weight}}\ x\ 100$$

6.2.1.2 Dry Samples analysis

a) Sample Preparation: Samples for analysis were prepared following the sun drying and grinding method mentioned above. For most of the analysis the standard procedure reported by Association of Official Analytical Chemistry (Latimer, 2012) was followed unless specified.

b) *Dry Moisture content (MCD%)*: The moisture content of the products was obtained by following standard analytical methods (Latimer, 2012). Triplicate samples (2 g) were weighed in previously weighed crucible dishes and oven dried for 16 hrs at 105 °C to constant weight. Loss of weight due to drying was converted to percent moisture content.

c) *Total ash determination*: Total ash content was determined using the Latimer (2012) procedure whereby 2.5g potato flour was weighed and burned on hot plate to complete smoke. This was followed by oxidizing the organic matter at higher temperature (550 ^{o}C) in a muffle furnace (Neytech Vulcan®, 3-550). The sample was left to ash until the residue was converted uniformly to white or nearly white. Total ash was determined as follows:

$$Ash\ (\%) = \frac{(\mathrm{W3} - \mathrm{W1})}{(\mathrm{W2} - \mathrm{W1})}\ x\ 100$$

Where: W_1 = weight of empty crucible

W_2 = weight of sample before ashing

W_3= weight of sample after ashing

d) *Crude protein*: Protein determination followed the modified Folin-Lowry method. This method employed the colorimetric procedure resulting in a Folin–Ciocalteau phosphomolybdotungstate to hetero-polymolybdenum blue complex. The resulting blue complex was measured using Ultra violate visible light spectrophotometer (UV-VIS) at a wavelength setting of 750 nm against external calibration standards prepared from bovine serum albumin (BSA).

e) *Phosphorus analysis*: Samples for P analysis were extracted employing the block digester following overnight digestion of samples using concentrated nitric acid and 30% hydrogen peroxide. Then the extracts were used to determine Phosphorus following the vandatemolybdate yellow method according to Latimer (2012). Absorbance was read at 400 nm using UV-VIS. Phosphorus content was estimated from a range of standards (0; 0.25; 0.5; 0.75; 1.0; 1.5 and 2.0 μg P/ml) calibration curve prepared from K_2HPO_4.

6.2.2 Data analysis

Data collected per cultivar and treatment (raw and boiled) were compared by one-way analysis of variance (ANOVA) using statistical package GenStat (12^{th} ed). The significance of differences between samples was evaluated by Duncan's multiple comparison ANOVA test, at the significance level p = 0.05 among cultivars and treatments. Correlation matrix was generated between the various nutritional traits and

the data was compared at $p< 0.05$. Results of the analysis were compared, ranked and presented in tables, graphs, charts and/or texts.

Table 6.1: Farmers' potato cultivars used for nutritional analysis.

Accession No.	Common Name	Village
1	Yeha	Geremi
2	Tsaeda Embaba I	Afdeyu
3	Keyh Embaba I	Afdeyu
4	Tsaeda_Embab II	Adiregit
5	Carneshim	Adiregit
6	Shashemanie I	Mendefera
7	Zafira I	SelaeDaero
9	Oval Sudan	SelaeDaero
10	Keyh Embaba II	Debarwa
11	Tsaeda Embaba III	Debarwa
16	Shashemanie II	Adi-Blay
18	Ajeba	Adi mongonti
19	Zafira II	Mendefera
20	Safira	AdiInadi
21	Grandinaine	Adi-Mongonti

6.3 Results and Discussions

6.3.1 Fresh samples

6.3.1.1 Total soluble solid (TSS ºBrix):

There were significant differences ($\rho<0.05$) among the samples in TSS content. Cultivar *Grandinaine* showed the highest level of TSS (9.5 ºBrix) followed by *Yeha, Shashemanie II, Zafira II* and *Safira* with TSS of (9.0 ºBrix), while *Keyh Embaba II* preceded by *Oval Sudan* showed the lowest levels of TSS with 7.7 and 8.0 ºBrix, respectively (Table 6. 2). Results from this study were similar to those of Abbas, Frooq,

Hafiz, Hussain, & Abbasi (2011) who reported significant differences among potato genotypes from Pakistan with respect to their reducing sugar contents. Changes in starch and sugar content are important in determining the sensory quality of potatoes (Katundu *et al*., 2007). Reducing sugars are typical components of potato, which are formed by the hydrolysis of starch, the major constituent of tubers (Gumul *et al*., 2011). Although the accumulation of reducing sugars is affected by environmental factors, it is termed as a heritable character (Abbas *et al*., 2011) which is consistent with the findings in this study. The relatively higher level of TSS in this study might be as a result of higher temperatures at harvest time and during storage at HAC. According to Katundu *et al*. (2007) there was a significant difference in the sugar content of varieties as a result of different storage methods. Moreover, it was reported by Daniel & Biniam (2016) that there were significant differences ($\rho<0.001$) of TSS level among the different potato varieties studied in Eritrea as affected by different potassium level application. High levels of reducing sugars have a negative impact on potato quality for processing as described by (Abbas *et al*., 2011).

6.3.1.2 Specific gravity

There were highly significant differences ($\rho<0.001$) among the cultivars in this study with respect to specific gravity. The mean values for this trait in the samples ranged between 1.09 (*Keyh Embaba I*) and 1.23 (*Yeha*) with an average of 1.15. Specific gravity of potato tuber is the quality parameter that represents its solid content (Kaul *et al*, 2010). Similarly, the high specific gravity content is an indication of good quality which is correlated with the content of dry matter and starch (Garnica H., Romereo B., Prieto C., Ceron L., 2012). The highest level of specific gravity was obtained from *Yeha* followed by *Tsaeda Embaba III* (1.22) and *Carneshim* (1.18) (Table 6.2). The range of specific gravity obtained from the current study corresponds with the findings of (Abbas *et al*., 2011; Chemeda *et al*., 2014; Garnica *et al*., 2012; Kaul *et al*., 2010). Abbas *et al*. (2011) reported that potato genotypes from Pakistan showed significant variation in their specific gravity value as studied for their processing quality. However, according

to Abong *et al*. (2009) although there was a trend of increase in specific gravity from 1.08 to 1.09, no significant differences were recorded among potato cultivars from Kenya.

Table 6.2: Mean values of biochemical analysis from fresh samples.

ACC	TSS (°Brix)	Specific Gravity	DMC (%)	MCF (%)
Yeha	9.00 ±0.50 bcd	1.23 ±0.05 g	16.67 ±2.66 f	83.33 ±2.66 ab
Tsaeda Embaba I	8.67 ±0.76 abcd	1.11 ±0.01 abc	15.47 ±0.81 cdef	84.53 ±0.81 abc
Keyh Embaba I	8.83 ±0.29 bcd	1.09 ±0.03 a	15.13 ±1.67 cdef	84.87 ±1.67 abcd
Tsaeda_Embab II	8.25 ±0.35 abcd	1.18 ±0.01 efg	16.60 ±0.10 f	83.40 ±0.10 ab
Carneshim	8.67 ±0.76 abcd	1.18 ±0.06 efg	15.13 ±0.50 cdef	84.87 ±0.50 abcde
Shashemanie I	8.50 ±0.87 abcde	1.16 ±0.02 cde	16.50 ±1.45 ef	83.50 ±1.45 ab
Zafira I	8.67 ±0.76 abcde	1.17 ±0.03 def	12.73 ±1.88 a	87.27 ±1.88 df
Oval sudan	8.00 ±0.77 ab	1.10 ±0.02 ab	13.40 ±1.10 abc	86.60 ±1.10 cdef
Keyh Embaba II	7.67 ±1.44 a	1.15 ±0.04 bcde	16.83 ±0.50 f	83.17 ±0.50 a
Tsaeda Embaba III	8.67 ±0.76 abcde	1.22 ±0.02 f	15.07 ±1.26 cdef	84.93 ±1.26 abcdef
Shashemanie II	9.00 ±0.50 bcde	1.16 ±0.03 cde	15.97 ±0.31 def	84.03 ±0.31 ab
Ajeba	8.17 ±0.29 abc	1.10 ±0.01 ab	12.76 ±0.49 ab	87.24 ±0.49 df
Zafira II	9.00 ±0.50 bcde	1.15 ±0.02 bcde	14.37 ±1.70 abcd	85.63 ±1.70 bcdef
Safira	9.00 ±0.64 bcde	1.12 ±0.02 abcd	15.70 ±1.24 def	84.30 ±0.0 abc
Grandinaine	9.50 ±0.00 e	1.16 ±0.01 cde	14.45 ±1.06 abcde	85.55 ±0.75 abcdef
Grand mean	**8.64**	**1.16**	**15.12**	**84.88**
LSD (ρ= 0.05)	**1.10**	**0.05**	**2.09**	**2.09**
CV%	**7.6**	**2.6**	**8.3**	**1.5**

Means with the same letter(s) within the same column are not significantly different at 5 % level of significance.

6.3.1.3 Dry matter content (DMC%)

The studied samples exhibited significant differences ($\rho<0.05$) in dry matter content with an average of 15.12%. Such a variation of dry matter content in potato cultivars was also reported by (Abong *et al*. 2009). As shown in Table 6.2 *Keyh Embaba II* followed by *Yeha* and *Tsaeda Embaba II* exhibited the highest level of DMC whereas

Zafira I preceded by *Ajeba* showed lowest level of DMC%. The average DMC % was lower than the report made by Abbas *et al*. (2011) and Garnica *et al*. (2012), which could be attributed to the high level of TSS as a result of storage temperature at Hamelmalo. As an important aspect of tuber quality, the dry matter content of potato tubers must meet a number of requirements for the processing industry (Garnica *et al*., 2012). Dry matter content of potato tubers with more than 20% of dry matter are good for processing of products such as chips, French fries and dehydrated products. However, this value is affected by environmental factors both at pre- and post-harvest levels as well as by variety (Chemeda *et al*., 2014).

6.3.2 Dried samples

6.3.2.1 Moisture content dry (MCD%):

The samples from raw potatoes showed highly significant differences ($\rho<0.001$) in moisture content among the studied materials with an average content of 13.21% and ranging from 13.97% (*Zafira II*) to 12.63% (*Keyh Embaba I*) (Table 6.3). Similarly, the materials showed significant differences in their MCD% content after boiling. The cultivar *Keyh embaba II* followed by *Tsaeda embaba II* showed highest level while *Grandinaine* showed lowest value. Moreover, there was a highly significant reduction ($\rho< 0.001$) in the MCD% as a result of boiling (13.56 to 12.86%). The results were in disagreement with those of Elfaki and Abbsher (2010) who reported that boiling had increased significantly in moisture content, although it was from fresh potato samples.

6.3.2.2 Total ash content (%)

The studied potato cultivars exhibited significant variation ($\rho<0.01$) in ash content when raw and after boiling. From the raw samples cultivar *Shashemanie I* showed the highest level of ash with (2.14%) while *Ajeba* (0.44%) showed the lowest level. But, from the boiled samples *Tsaeda Embaba II* (1.77%) and *Zafira II* (0.08%) showed highest and lowest levels, respectively (Table 6.3). Similar findings of significant variation among

genotypes was reported earlier by (Abbas *et al*., 2011; Abong *et al*., 2009; Chemeda *et al*., 2014; Gumul *et al*., 2011). The average ash content of raw tubers from this study (1.4%) on dry weight basis (DWB) is pretty much similar to the findings by Odebunmi *et al*. (2007). However, Gumul *et al*. (2011) obtained ash content of 3.95-4.71% per 100g of dry weight; Garnica *et al*. (2012) reported 0.6-1.9% while Abong *et al*. (2009) reported 0.94% on fresh weight basis (FWB). This wide variation of ash content might be a result of varietal differences as reported earlier by Abbas *et al*. (2011).

Moreover, it was noted from the current study that boiling of tubers reduced ash content highly significantly ($\rho<0.001$) from 1.40 to 0.76% (Figure 6.1 & Table 6.3). Similar reduction of ash content as a result of boiling was reported by Abong *et al*. (2009). While insignificant decrease of ash content by boiling (0.83 to 0.50%) was reported by Elfaki and Abbsher (2010). This reduction is partly attributed to the leaching of the ash into the cooking water.

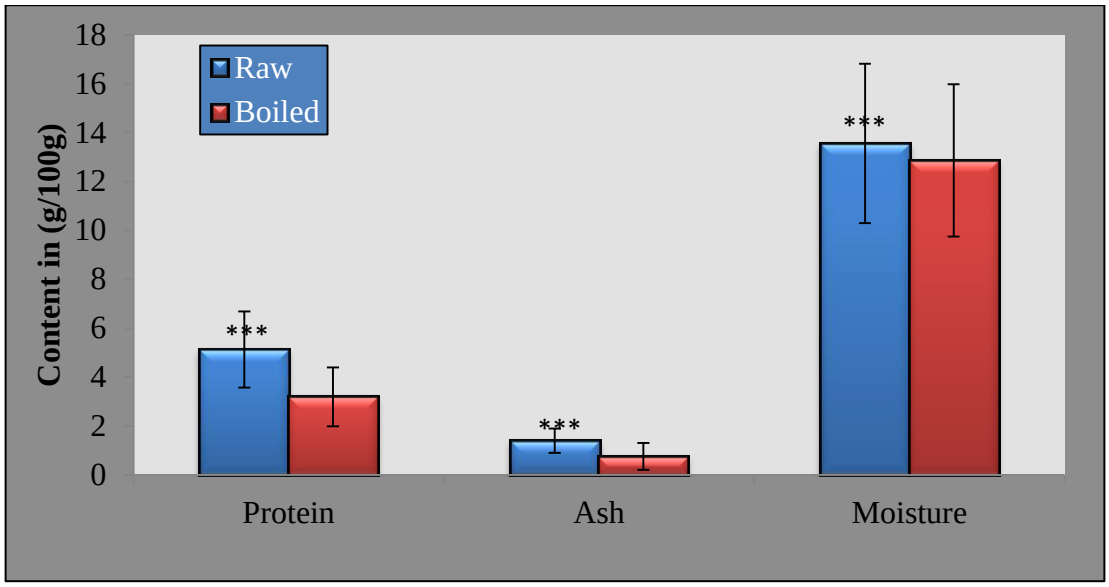
6.3.2.3 Crude protein

The current study revealed that there were highly significant differences ($\rho<0.001$) both among the samples and treatments (raw vs boiled). The highest and lowest values obtained from the studied cultivars with a significant variation among them are shown in Table 6.3. Significant differences among cultivars on crude protein content had also been reported by other authors (Abbas *et al*., 2011; Abong *et al*., 2009; Chemeda *et al*., 2014; Gumul *et al*., 2011). Further, Bartova *et al*. (2009) reported that the most important factor affecting crude protein content was cultivar (genetic) with approximately 34% variation between genotypes.

Table 6.3 shows the average values of raw and boiled crude protein content where *Safira* (8.9 g/100g) followed by *Shashemanie I* (7.1 g/100g) showed highest level of raw crude protein while *Zafira II* (3.2 g/100g) preceded by *Carneshim* (3.8 g/100g) contained lowest protein levels from raw tubers. Previously, Chemeda *et al*. (2014)

reported that they obtained crude protein levels ranging between 5.8 to 7.68 % on dry weight basis (DWB). Similarly, Bartova *et al*. (2009) reported crude protein content (N x 6.25) ranged from 5.86 to 11.16% of potato tuber on a DWB, while Abong *et al*. (2009) reported an average of 1.89% on a fresh weight basis (FWB) and 8.4% on a DWB. Yet, Odebunmi *et al*. (2007) reported 4.74% and 22.4% on FWB and DWB, respectively. On average, results in this study indicate lower than the aforementioned values but higher than the reports made by Abbas *et al*. (2011) ranging between 0.72-3.4% and Garnica *et al*. (2012) ranging between 0.7-4.1%. The wide variation in reports on the crude protein content by different researchers might be attributed to the different materials used as well as to the nitrogen fertility of the soil under which they were grown as there is direct relationship between N dose application and crude protein content (Bartova *et al*., 2009).

Moreover, although the level and trend varied from sample to sample, the current study revealed that boiling of the potato tubers significantly ($\rho<0.001$) reduced the average level of protein content from 5.13 to 3.19 g/100g (Figure 6.1). This result is in agreement to the report made by Prokop and Albert (2008) where a reduction of protein upon boiling was reported. Yet, the protein content was decreased by boiling, although insignificantly (Elfaki & Abbsher, 2010). The authors added that the composition and nutrient contents of potato products vary depending on the method of cooking used. Prokop and Albert (2008) reported that the main reason for the reduction is as a result of leaching into cooking water and oil, destruction by heat treatment or chemical changes such as oxidation. On the other hand, Abong *et al*. (2009) reported no significant effect of boiling and frying on crude protein content when compared with raw tubers.



*** significant difference (ρ<0.001)

Figure 6.1: Nutritional content of raw and boiled potato cultivars.

Table 6.3: Mean values of nutritional analysis from dry samples.

ACC	Protein (g/100g)		Ash (g/100g)		Dry Moisture content (%)	
	Raw	Boiled	Raw	Boiled	Raw	Boiled
Yeha	bc 4.4 ±0.3	de 3.9 ±0.1	gh 1.79 ±0.02	g 1.22 ±0.08	bc 13.29 ±0.03	bcde 12.81 ±0.08
Tsaeda Embaba I	cd 4.9 ±0.1	de 3.8 ±0.4	d 1.2 ±0.02	de 0.62 ±0.01	bc 13.25 ±0.15	def 12.88 ±0.2
Keyh Embaba I	bc 4.5 ±0.1	g 4.9 ±0.4	e 1.39 ±0.03	abc 0.19 ±0.02	a 12.63 ±0.17	bcde 12.8 ±0.03
Tsaeda_Embab II	bc 4.3 ±0	cd 3.6 ±0.3	hi 1.89 ±0.01	i 1.77 ±0.11	b 13.14 ±0.18	gh 13.1 ±0
Carneshim	ab 3.8 ±0.1	def 4.2 ±0.1	fg 1.66 ±0.09	d 0.53 ±0.01	de 13.74 ±0.26	bcd 12.77 ±0.16
Shashemanie I	e 7.1 ±0.7	c 3.1 ±0.1	j 2.14 ±0.23	h 1.5 ±0.02	f 14.09 ±0.03	cdef 12.86 ±0.02
Zafira I	bc 4.1 ±0.4	c 3.2 ±0.3	b 0.78 ±0.05	c 0.31 ±0	def 13.79 ±0.11	efg 12.97 ±0.08
Oval sudan	d 5.5 ±0.4	fg 4.6 ±0.3	f 1.55 ±0.03	f 0.87 ±0.06	cd 13.48 ±0.01	abc 12.67 ±0.03
Keyh Embaba II	bc 4.4 ±0.1	a 1.5 ±0.1	c 0.99 ±0.06	g 1.2 ±0.09	bc 13.29 ±0.12	h 13.24 ±0.05
Tsaeda Embaba III	e 6.7 ±0.6	a 1.6 ±0.1	b 0.77 ±0.01	ab 0.15 ±0	ef 13.94 ±0.13	fg 13.05 ±0.07
Shashemanie II	bc 4.4 ±0.3	b 2.1 ±0.1	gh 1.78 ±0.12	h 1.49 ±0.11	bc 13.24 ±0.2	ab 12.66 ±0.07
Ajeba	bc 4.1 ±0.3	a 1.2 ±0.1	a 0.44 ±0.02	bc 0.23 ±0	ef 13.89 ±0.03	efg 12.97 ±0.01
Zafira II	a 3.2 ±0.1	b 2.2 ±0.2	bc 0.88 ±0.06	a 0.08 ±0	ef 13.97 ±0.07	def 12.88 ±0.05
Safira	f 8.9 ±0.3	ef 4.3 ±0.3	f 1.56 ±0.07	d 0.55 ±0.03	de 13.7 ±0.08	bcd 12.74 ±0.1

Grandinaine	e 6.8 ±0.4	de 3.9 ±0.1	ij 1.99 ±0.05	e 0.69 ±0.04	ef 13.9 ±0.16	a 12.54 ±0.04
Grand mean	**a** 5.13**	**b 3.19**	**a** 1.40**	**b 0.76**	**a** 13.56**	**b 12.86**
LSD between rows (5%)	**0.153**		**0.065**		**0.059**	

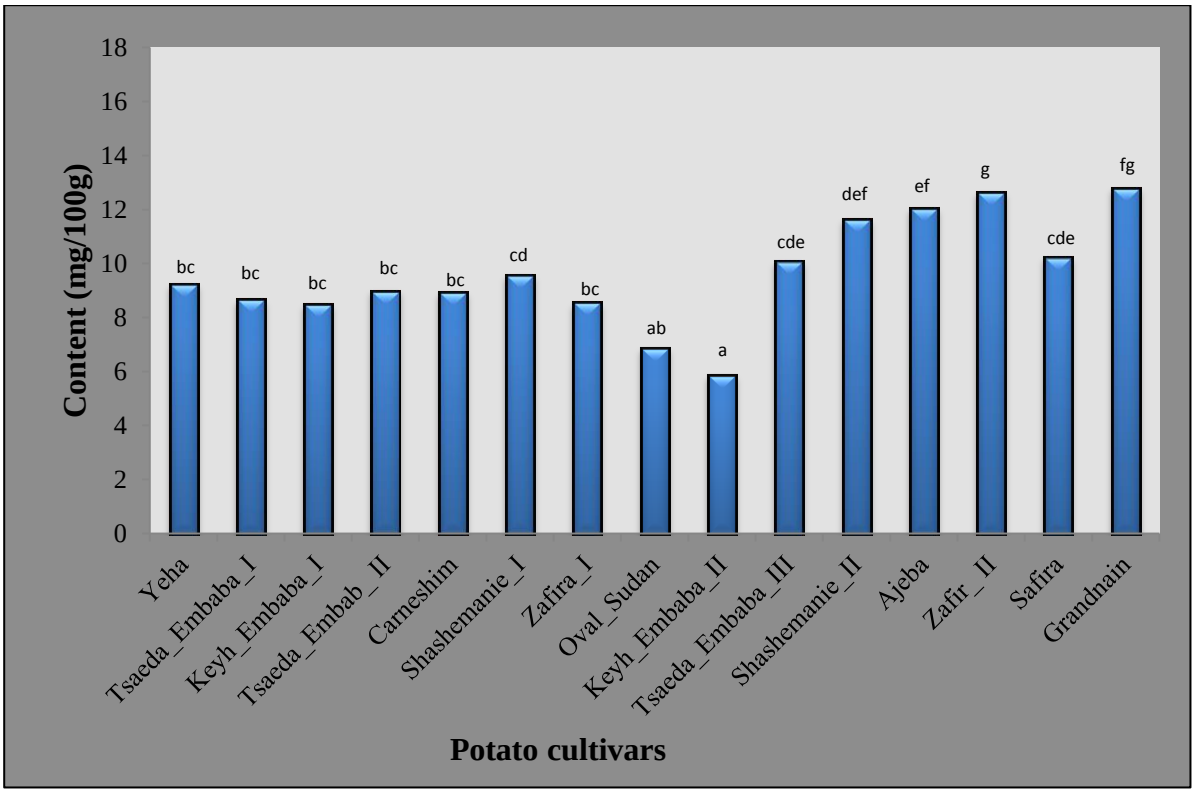
*= significant difference (ρ<0.05); **=highly significant difference (ρ<0.001);

Means with the same letter(s) within the same column are not significantly different at 5 %level of significance.

6.3.2.4 Phosphorous (P)

There was a highly significant difference (ρ<0.001) between the potato cultivars in their P content where *Zafira II* followed by *Grandnain* and *Ajeba* showed highest levels while *Keyh Embaba II* preceded by *Oval sudan* contained lowest level of P (Figure 6.2). The presence of mineral elements is necessary for the maintenance of certain physiochemical conditions, which are essential for life (Ikanone & Oyekan, 2014). The current finding is consistent with a previously reported phosphorous content in potato by Abong *et al*. (2009) and Chemeda *et al*. (2014) where there was significant varietal difference. The variation of minerals has been attributed, among others, to soil type, soil pH, application of fertilizers and potato variety (Abong *et al*. 2009; (Haan & Rodriguez, 2016).

Moreover, the P level was reduced significantly (ρ<0.05) upon boiling of tubers. Previously, Abong *et al*. (2009); Bethke and Jansky (2008); Ikanone and Oyekan (2014) reported that P content was significantly reduced as a result of potato tuber boiling. Minerals are not destroyed in food preparation; however, some losses will occur as a result of leaching if cooking liquids are discarded (Ikanone & Oyekan, 2014). Similarly, it was reported that the method used to prepare food influences its nutritional content in general and minerals in particular (Bethke & Jansky, 2008). It was also noted that the P content from the current study was lower in value as compared to most other reports which could be partly attributed to the variety, soil fertility, fertilization and pre and postharvest handling practices.



Means with the same letter(s) are not significantly different at 5 %level of significance.

Figure 6.2: Phosphorous content of tubers from different potato cultivars.

6.3.3 Quality traits of cultivars

The current study revealed that some of the studied potato cultivars have shown promising level of quality traits for protein (47%), for DMC % (60%) and for P (40%) higher than their mean average (Table 6.4). This is a relevant input for breeders and policy makers in making informed decision for future breeding programs.

Table 6.4: Cultivars with higher nutritional qualities than the mean average.

	Protein	DMC%	Phosphorus
Cultivars with above mean average values	*Yeha, Keyh_Embaba I, Tsaeda Embaba I, Shashemanie_I, Oval sudan, Safira, Grandnain*	*Yeha, Keyh_Embaba I, Tsaeda Embaba I, Tsaeda_Embaba II, Carneshim, Keyh_Embaba II, Shashemanie I, Shashemanie II, Safira*	*Tsaeda Embaba III, Shashemanie II, Ajiba, Zafira_II, Safira, Grandnain*

6.3.4 Correlation coefficients

A matrix was generated to identify correlation coefficient so as to estimate correlation between the various nutritional quality traits. It was noted that ash content showed a positive correlation with DMC% (0.68), with protein content (0.34) and with SG (0.26) while equally negative correlation with MCD% as well as with MCF% (Table 6.5). The positive correlation between protein and ash content as well as negative correlation between protein and SG in this study corresponds to the report made by Garnica *et al*. (2012). However, opposite to their findings, there was weak positive correlation between protein and dry mater content (DMC%). It was also evident from the Table 6.5 that SG was positively related with DMC% (0.38). Positive correlation of specific SG previously by Abbas *et al*. (2011) and Garnica *et al*. (2012), respectively. However, in contrast to our finding Abbas *et al*. (2011) reported negative correlation to reducing sugars (r = -0.2310). Similarly, yield per plant was positively related with MCD%, SG while negatively related to protein content (Table 6.5).

Table 6.5: Correlation coefficient matrix of the studied variables

Variables	Ash	DMC%	MCD%	MCF%	P	Protein	SG	TSS
DMC%	0.68**							
MCD%	-0.33*	-0.26*						
MCF%	-0.68**	-1.00**	0.26*					
P	-0.21*	-0.25*	0.29*	0.25*				
Protein	0.34*	0.16*	-0.20*	-0.16*	-0.17*			
SG	0.26*	0.38*	0.31*	-0.38*	NS	-0.15*		
TSS	NS	NS	-0.15*	NS	0.64**	0.33*	0.23*	
Yield	NS	NS	0.44*	NS	0.19*	-0.13*	0.70**	0.17*

Where: DMC%= dry matter content; MCD% = dry moisture content; MCF%= fresh moisture content; P= phosphorus; SG= specific gravity; TSS= total soluble solids; ** highly significant at $\rho<0.01$; * significant at $\rho<0.05$

6.4 Conclusion

The results indicated that the potato cultivars in Eritrea widely vary with respect to their nutritional qualities. The finding rejects the null hypothesis. The variation could be attributed to genetic as well as environmental and processing methods. The finding is the first of its kind providing basic nutritional information on raw and boiled potato products from Eritrea which has never been addressed adequately before. Boiling considerably reduced the nutritional content of most studied traits. The local potato materials such as *Yeha, Tsaeda Embaba, Safira* and *Shashemanie* were identified with some quality nutritional traits useful for future breeding programs in addressing food and nutrition security in the country.

CHAPTER SEVEN

GENERAL CONCLUSIONS AND RECOMMENDATIONS

7.1 General Conclusions

Potato is an integral part of growers and consumers in Eritrea, but with a very limited knowledge to its genetic identity and nutritional value. Its productivity and hence availability in the market is getting scanty from time to time. The diagnostic survey indicated that majority of the growers are small scale with low input low output scheme. It was also noted that farmers use limited amount and types of fertilizers, which negatively affects productivity. There is acute shortage of farm inputs, including quality seed tubers, resulting in informal distribution system. Framers are, thus, obliged to use own seed for several generations. The survey further revealed that the main insect pests causing economic damage to the crop are cut worm, aphids and Potato Tuber Moth (PTM) while late blight, common rust and *Fusarium* wilt infection are among the leading disease causing pathogens posing serious yield damage. Farmers attempt to control the pest pressure using chemical means followed by cultural method. The diagnostic survey further identified the major potato production constraints in Eritrea. They can be summarized as biological (pathology, entomology and virology); agronomic (poor soil fertility, insufficient water, topography,) and socioeconomic (limited input availability, lack of marketing infrastructure, limited land size, low commodity price, labour cost, consumer preference). It is, however, noteworthy mentioning that the degree and level of constraints and potentials vary considerably across the two Zobas studied indicating locational solutions and recommendations should be formulated accordingly.

The morphological and molecular characterization helped in identifying similarity and/or diversity between the potato cultivars. Both the approaches revealed that there were no purely identical materials including between the materials with same name given by the farmers thus rejecting the null hypotheis. Moreover, it was noted that

materials from the same geographic location may not necessarily share the same genetic content. However, some closely related materials with >99% Euclidean similarity level were identified. Yet, the cluster analysis based on morphological descriptors indicated that all the cultivars share 92% Euclidean similarity level. The mean value deviation of variables for each group from the total mean indicated that most of the materials from Group I and II contained the preferred traits for future crop improvement.

The molecular analysis revealed that the farmers' materials studied were not pure collections as duplicate of the same collections did not show 100% similarity indicating that they are mixed up and need cleaning. The samples from Eritrea showed some degree of distinctness from the samples from Kenya and Rwanda. The analysis further indicated the Eritrean potato germplasm could be of Tuberosum origin from European but not Andigenum origin. Moreover, the farmers' cultivars exhibited more diverse than the recently introduced varieties which can therefore be exploited for breeding.

The study also revealed that cultivars widely vary with respect to their nutritional qualities as affected genetically and by environmental factors including processing methods. Boiling significantly reduced the nutritional content of most studied traits. Very promising content of protein and dry matter content was noted with some local materials (*Yeha, Tsaeda Embaba, Safira* and *Shashemanie*) that can be considered for future breeding policy.

7.2 General Recommendations

Baseline survey was conducted aiming at collecting and documenting basic potato farming systems in Eritrea. The survey provided useful information to harness for possible yield optimization. Similarly, major constraints limiting the productivity of potato were identified as point of entry for future intervention. Moreover, the identity and nutritional analysis have recognized materials containing preferred traits for future breeding program. Thus, to improve and optimize potato productivity, in Eritrea, the following recommendations are drawn:

- Sustainable and standard seed supply scheme should be established.
- Supply of timely and reasonably priced farm inputs (pesticide, fungicide, fertilizers, farm equipment) should be secured.
- Frequent extension and technical advice services should be provided to farmers.
- Further characterization of the materials based on their resistance to late blight disease would enrich the existing base line information.
- Establishing germplasm conservation scheme is essential as many of the farmers' potatoes are disappearing and even the existing ones are available only in a handful of farmers.

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APPENDICES

Appendix 1

Individual Household (HH) Questionnaire on Potato Production in Eritrea.

Q. No. _____
Date:_____/____/ 201_____

Section I: General Household information

1.Zoba ---------- Sub zoba----------

2.Village administration ---------- Village----------

3.Altitude ----------

4.Latitude ---------- Longitude ----------

5.Farmer's name---------- Family size----------

6.Age ----------

7.Sex ----------

8. Educational level: Illiterate ☐ Elementary ☐ Junior ☐ High school ☐ College ☐

Section II: Cropping Systems

1. How many years have you been growing potato_____
2. How did you acquire the land: Risty ☐ Diesa ☐ Rent ☐ Other……..
3. How many hectares of land do you own?
   3.1 _____ ha (rain-fed) or _____ Tsimdi
   3.2 _____ ha (irrigation) or _____ Tsimdi
4. How many hectares of land do you cultivate annually with potato?
   4.1 _____ ha (rainfed) or _____ Tsimdi
   4.2 _____ ha (irrigation) or _____ Tsimdi

☐ ☐ ☐

5. Type of soil: Clay ☐ Sandy loam Loam Silt clay ☐ Sandy clay Other

6. Topography: Flat ☐ Gentle slope ☐ Steep slope ☐ Other……

7. Irrigation system: Drip ☐ Furrow ☐ Overhead ☐ Other ……

8. Source of water: Well ☐ Stream ☐ Dam ☐ Other----------

   8.1. Availability of water: Little ☐ Moderate ☐ Plenty ☐

9. Land preparation?

   Manual ☐ Animal ☐ Tractor ☐ Combination ☐

10. Seeding rate (tons/Ha)

    10.1 For seed potato ----------

    10.2For ware potato ----------

11. Planting period

    11.1. Irrigated: Summer ☐ Autumn ☐ Winter ☐ Spring ☐

    11.2. Rain fed: Summer ☐ Autumn ☐ Winter ☐ Spring ☐

12. Harvesting period

    12.1. Irrigated: Summer ☐ Autumn ☐ Winter ☐ Spring ☐

    12.2. Rain fed:- Summer ☐ Autumn ☐ Winter ☐ Spring ☐

13. Planting of tuber: Cut ☐ whole ☐

    13.1 Why ----------

14. Time taken to maturity: 3 M ☐ 4 M ☐ 5M ☐ 6M ☐ 7 M ☐

15. Describe production status of potato in your fields in the last five years?

	2009			2010			2011			2012			2013		
	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
Rainfed															
Irrigated															

16. Average Yield (tons/ha)

16.1. Irrigated----------

16.2. Rain fed ----------

17. Which farming system gives best result----------

18. Do you practice crop rotation used Yes ☐ No ☐

18.1. If yes describe how and why

……..

……

……

19. Do you practice inter cropping: Yes ☐ No

If yes, explain:……..

20. Fertilizer: DAP ☐ Urea ☐ Potash ☐

Other…….

21. Source of Fertilizer: MOA ☐ Market ☐ Friends ☐ Other ……

22. When do you use more fertilizer: Irrigated ☐ Rain fed ☐

23. Do you think the supply of fertilizer is adequate? Yes ☐ No ☐

24. Insecticides used (underline): *Parathion Benzolate Cyhalothrin Malathion Zulfo*

Other……

25. Type of fungicides used (underline):*Mancozeb Ziram Ferbam Methyl mercury Maneb* Other……

26. When are insecticides and fungicides mainly used? Rain fed ☐ Irrigated ☐

27. Source of input: MOA ☐ Market ☐ Friends ☐ Other ……

Section III: Seed source and use system

1. Source of seed: Own ☐ MOA ☐ Market ☐ Friends ☐ Other……
2. Status of seed: Basic ☐ Foundation ☐ Certified ☐ Commercial ☐
3. Familiar varieties used: *Carneshim T. Embaba K. Embaba Spunta Ajiba Desiree Cosmos Picasso* other…….
4. Frequency of variety used: Last 20 yrs Last 10 yrs Last 5 yrs Very recently
5. Preference of variety/varieties: *Local Spunta Ajiba Desiree Cosmos Picasso*

   5.1. Why are they preferred: *Market Taste Resistance Yield* Other…….
6. What color of flower is preferred: White ☐ Red ☐ Pink ☐ Other ……

   6.1 Why ----------
7. How do you identify the varieties: Flower ☐ Tuber colour ☐ Tuber Shape ☐ Other ----------
8. Do you practice seed Pre-sowing treatment? Yes ☐ No ☐

   8.1 If yes how ----------

9. Do you have seed storage facility Yes ☐ No ☐

   9.1 If yes describe----------

Section IV: Pest prevalence

1. Common insect pest prevalent during growth period in the area (underline)
   Beetle Cut worm Army worm Grasshopper Aphid Spider mite White flies Thrips Other……
2. Control measures taken: Cultural ☐ Biological ☐ Physical ☐ Chemical ☐
3. Are the insecticides efficient for control of insect pest?; Yes ☐ No ☐
   if no, explain ----------
4. Common diseases in the area (underline): *Late blight Early blight Fusarium wilt Common rust Gangrene Gray mold Powdery mildew* PVS PVX PVM PVY PYV

   Other:
5. Control measure taken: Cultural ☐ Biological ☐ Physical ☐ Chemical ☐

Section V: Marketing

1.End use of potato: Cooked ☐ Chips ☐ Boiled ☐ Other……..

2.Potential buyers/Market

Wholesalers ☐ Retailers ☐ Consumers ☐ Other ……

3.Selling price of Potato (per kg): Wholesaler……. Retail……Consumer ……

4.How far is the market place from your area……..km

5.What transportation system do you use? Public ☐ Own ☐ Hired ☐ Other

*6.*Preferred tuber form and color: *Round white Round yellow Round red Oval white Oval red Oval yellow other……*

6.1 Why ----------

7.Market preference from consumer point of view: ----------

Section VI: List of Constraints and /or Potentials

Please rank the major constraints and potentials lists according to their degree of severity

Lists	**Constraint Ranking**			**Potential Ranking**	
	Very much	Somewhat	Neither	Somewhat	Very much
Water availability and access					
Land availability					
Seed source and availability					
Labour availability and cost					
Transportation					
Fuel					
Market					
Diseases					
Insects					
Weeds					
Rainfall					

Filled by:_____

Annex 4.1: Detail information of the descriptors used and their coding

Vegetative

Days to emergence
3 Early
5 Medium
7 Late

Number of the Primary Stem
1 Single
2 Few (1 – 3)
5 Medium
7 Many

Stem Colour
1 Green only
2 Red-brown only
3 Purple only
4 Cream with some red–brown
5 Cream with purple
6 Red–brown with some green
7 Purple with some green
8 Other

Stem Cross Section
1 Round
2 Angular

Stem Wing
0 Absent
1 Straight
2 Undulate
3 Dentate

Plant Height at Flowering Stage
3 Short
5 Medium
7 Tall

Branching Habit
1 Single
2 Branching

Growth Habit
1 Erect
2 Semi–erect
3 Decumbent
4 Prostrate
5 Semi–rosette
6 Rosette

Lateral leaflet numbers
0 Absent
1 One pair
2 Two pairs
3 Three pairs
4 Four pairs
5 Five pairs
6 Six pairs
7 Seven or more pairs

Interjected leaflets number in the rachis among lateral leaflets
0 Absent
1 One pair
2 Two pairs
3 Three pairs
4 Four or more pairs

Predominant Sprout Colour
1 White-green
2 Pink
3 Red
4 Violet
5 Purple
6 Other

Secondary Sprout Colour
0 Absent
1 White–green
2 Pink
3 Red
4 Violet
5 Purple
6 Other

Distribution of Secondary Sprout Colour
0 Absent
1 At the base
2 At the apex
3 Lightly scattered throughout
4 Heavily scattered throughout
5 Other

Biotic Stress
1 Extremely resistant
2 Highly resistant
3 Very resistant
4 Resistant
5 Moderately resistant
6 Slightly resistant – slightly susceptible
7 Moderately susceptible
8 Susceptible
9 Extremely susceptible but adapted as necessary to each specific Disease

Flowering

Predominant Flower Colour
1 White
2 Light red
3 Intense red
4 Light blue
5 Intense blue
6 Light purple
7 Intense purple
8 Yellow

Secondary Flower Colour
0 Absent
1 White
2 Light red
3 Intense red
4 Light blue
5 Intense blue
6 Light purple
7 Intense purple

Distribution of Secondary Flower Colour
0 Absent
1 White acumen – adaxial surface
2 White acumen – abaxial surface
3 White acumen or both surfaces

Degree of Flowering
0 No buds
1 Bud abortion
3 Flowering scarce
5 Flowering moderate
7 Flowering profuse

Duration of Flowering

Reproductive

Predominant Tuber Skin Colour
1 White-cream
2 Yellow
3 Orange
4 Brownish
5 Pink
6 Red
7 Purplish–red
8 Purple
9 Dark purple-black

Secondary Tuber Skin Colour
0 Absent
1 White–cream
2 Yellow
3 Orange
4 Brownish
5 Pink
6 Red
7 Purplish–black
8 Purple
9 Dark purple–black

Distribution of Secondary Tuber Colour
0 Absent
1 Eyes
2 Eyebrows
3 Splashed
4 Scattered
5 Spectacled
6 Stippled
7 Other

Tuber Skin Type
1 Smooth
2 Rough (flaky)
3 Partially netted
4 Totally netted
5 Very heavily netted

3 Short
2 Medium
7 Long

Number of Flowers per Inflorescence
1 Single
2 Few (2 – 5)
3 Intermediate number
4 Many (more than 20)

WEEKS TO FLOWERING
Counted as the number of weeks from emergence to flowering and recorded when 50% of the plants of an accession are flowering

6 Other

Predominant Tuber Flesh Colour
1 White
2 Cream
3 Yellow – cream
4 Yellow
5 Red
6 Violet
7 Purple
8 Other

Secondary flesh colour
0 Absent
1 White
2 Cream
3 Yellow – cream
4 Yellow
5 Red
6 Violet
7 Purple
8 Other

Distribution of Secondary Tuber Flesh Colour
0 Absent
1 Scattered spots
2 Scattered areas
3 Narrow vascular ring
4 Broad vascular ring
5 Vascularring medulle (pith)
6 All flesh exept medulla (pith)
7 Other

General Tube shape
1 Compressed (oblate).
2 Round
3 Ovate.
4 Obovate
5 Elliptic
6 Oblong
7 Long-Oblong.
8 Elongate

Depth of Tuber Eyes
1 Protruding
2 Shallow
3 Medium
4 Deep
5 Very deep

Maturity time
Recorded when 50% of the plants of an accession are ready for harvest, and indicated by the senescence of vines against a standard local commercial variety
3 Early
5 Medium
7 Late

TUBER CHARACTERISTICS

Tuber Set
Number of tubers per hill
3 Low
5 Medium
7 High

Tuber Size
3 Small
5 Medium
7 Large

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DIAGNOSTIC SURVEY ON POTATO PRODUCTION PRACTICES IN ERITREA

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ABSTRACT

A baseline survey was conducted in Zoba Maekel and Zoba Debub, Eritrea, to determine existing potato production practices and identify areas of intervention for optimization of its productivity. The study will contribute to improved food security and livelihood of poor farmers in the country. Within each Zoba, the Sub-zoba/village (strata) was purposely selected based on their history and coverage in potato growing, while farms (sites) were randomly selected for the study. Farmer respondents were interviewed (by enumerators) based on a comprehensive set of questions on their potato growing practices. Useful information, on house hold characteristics, farm land and crop management practices, seed source, rotation, irrigation and fertilization methods, weed, pest and disease management, and yield were collected. In addition, to structured questionnaires focus group discussion with groups of selected farmers was conducted. Although, the degree and level might vary from growers to growers and Zoba to Zoba, it was noted from the survey that growers face major challenges in obtaining farm inputs especially quality tuber seeds, fertilizers and pesticides. Moreover, pest prevalence particularly, Cut Worm infestation (87%) and Late Blight infection (97%) were observed throughout the visited villages posing major problem to growers. It is, therefore, recommended to secure availability of major farm inputs and provide frequent extension services to improve farmer's knowledge and understanding. Especially, consideration should be given to the establishment of sustainable and standard seed supply scheme at all levels.

Keyword: potato, Eritrea, farming systems.

INTRODUCTION

Agriculture is the mainstay for more than 70% of Eritrea's population and one of the most important economic sectors of the country. The main food crops grown include: wheat, barley, maize, sorghum and pearl millet, and many forage and horticultural crops. One of the common vegetable crops grown is potato. It grows widely in the highland part of the country, mainly by small scale farmers with low input low output practice with an estimated area of 24, 000 ha and production of 285, 339 tones per year. It is grown both for home consumption as well as for cash. Because of this double purpose, the potato crop plays an important role in the rural livelihood system of many countries (Gildemacher, 2012).

In Eritrea, potato production is concentrated mainly in the highlands of the country, more particularly in Zoba Maekel and Zoba Debub. It is a key component in the livelihood systems of small-scale farmers in these regions. The crop is grown both under rain fed and irrigated condition often in small parcels of lands with limited resources. The production and thus supply of potato in the market flucatuates from time to time. As a result, the price soars from day to day. A careful understanding of the context is, therefore, important to identify the core problem and hence find ways how to enhance productivity and stabilize the situation. It has been demonstrated that, quantitative and qualitative surveys help to understand the potato farming system (McPharlin and Taylor, 2005). Furthermore, for improved productivity of potato, it is essential that farming systems are understood in order to identify and implement necessary intervention.

Baseline survey on potato crop has been conducted in many countries such as Kenya, Ethiopia and Uganda (Gildemacher, 2012); Kenya (Muthoni and Nyamongo, 2009; Muthoni, *et al*., 2013); India (Kadian *et al*., 2010); Ecuador (Barrera and Norton, 1999), Indonesia (Dawson, *et al,* 2005), Argentina (Caldiz, 2000). According to Gildemacher, *et al*., (2009), for instance, for effective targeting of research and development efforts, a more detailed country or region specific analysis of the potato system and its potential opportunities and possible constraints is required. The survey not only helps to identify relevant areas of intervention, but also helps to identify weaknesses within the system that need to be revised immediately. However, no survey study was conducted in Eritrea to study the current potato production system practices.

The current study is, thus, designed to gather and document potato cultivation system in Eritrea with particular emphasis on land management systems prevailing in the area, household and farm characteristics, cropping pattern, cultural practices, pests and their control, and yield. It was envisaged that the information gathered would assist in the identification of the main areas of intervention for planning future potato production activities in order to improve productivity and hence livelihood of growers.

MATERIALS AND METHODS

The study was conducted in the two major potato producing Zobas (regions) of Eritrea (Zoba Maekel, and Zoba Debub). Zoba Maekel, the smallest of the six Zobas of Eritrea, lies between 15°10' - 15°35'N latitude and

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Scientific Research

Potato Seed Supply, Marketing and Production Constraints in Eritrea

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Abstract

Potato is an important vegetable crop in Eritrea contributing significantly to food security. Despite its importance, however, production and thus supply of the crop in the market are limited. The current study is designed to understand the seed supply system, marketing out lets and major production constraints. The survey was conducted in the two main potato producing Zobas of the country (Zoba Maekel and Zoba Debub). Qualitative and quantitative data was generated using focus group discussion (PRA) and semi structured questionnaire, respectively. A total of 20 villages were visited and 138 farmers were interviewed. The finding revealed that there is no standard seed supply system thus majority (91.3%) of the growers purchase seed from open market with a limited supply from the Ministry of Agriculture. Furthermore, about 63% of the farmers from Zoba Maekel reserve their own seed for the next cycle compared to 53.6% from Zoba Debub. It was noted that the *Tsaeda embaba* variety grows predominantly in the country owing to its yield and resistance. Majority of the growers rely on tuber colour and shape for variety identification, thus over 76% prefer the round shaped and white coloured variety. The potential marketing outlets include wholesale, retailer and direct to consumers. Majority (78.3%) of the interviewed growers indicated that large portion of their produce is marketed via wholesaler followed by retailers (27.5%). Main production limiting constraints are identified as low input supplies, availability and cost of clean seeds, pest pressure while huge market demand and access to transportation are considered as potentials encouraging grower. It is, therefore, recommended that an immediate action to establish sustainable seed supply system is taken into consideration in line with a regular extension service to provide technical advice to growers.

Keywords

Potato, Seed Source, Marketing, Constraints, Potentials

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Analysis of Diversity among Potato Accessions Grown in Eritrea Using Single Linkage Clustering

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Abstract

Potato is an important cash and food crop, a source of income to many small scale farmers in Eritrea. In the long tradition of potato cultivation farmers have adopted a number of landraces. However, very little is known about their genetic diversity which limits further breeding programs to improve productivity. The objective of the study was to characterize potato accessions grown in Eritrea. A total of 21 accessions collected from farmers and NARI were used in this study for characterization employing 33 phenotypic descriptors. Single linkage (nearest neighbor) clustering method using UPGMA employing Euclidean test was used to yield a dendrogram. The clustering generated three main clusters with further sub clusters. The clustering helped to identify accessions that shared the same characteristics and/or that were closely related and *vice versa*. It was noted that there was no distinct relationship between the clusters groups and geographic sources of accession. Yet, accessions sharing the same name may not necessarily share the same genetic content. Mean deviation of variables for each group from the total mean indicated that Group III followed by group I showed negative deviation in most of the recorded yield related traits. Group I was particularly affected by the presence of two inferior accessions in the group. On the other hand, Group II accessions showed relatively maximum deviation from the total mean and could be recommended for use as parent for any breeding program in Eritrea.

Keywords

***Solanum tuberosum*, Potato, Eritrea, Morphological Traits, Cluster, Diversity**

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Morphological Diversity of Farmers' and Improved Potato (*Solanum tuberosum*) Cultivars Growing in Eritrea

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Abstract

Farmers' and improved potato (*Solanum tuberosum* L.) cultivars growing in Eritrea are main sources of food and income to many growers. The current study was proposed to characterize 17 farmers' and 4 imported cultivars of potato using 33 morphological descriptors. Planting was done in two geographically distinct locations, HAC and Asmara, Eritrea. The experiment was laid out in a randomized complete block design with three replications having 18 plants per plot. Plants grown at HAC emerged early (24.52 days) and reach maturity (94.84 days) while at Asmara it took 43.77 and 123.59 days, respectively. However, yield was higher in Asmara (0.49 kg/plant) compared to HAC (0.37 kg/plant). An accession having many and longer stems was associated with more tuber production, but inversely related to yield. Similarly, accessions with higher stem thickness and tuber size were associated with high yields. The PCA analysis indicated that the first four components explained about 85% of the total variability among the studied materials. The PCA clustered the materials in to four main groups (GI, GII, GIII, GIV) mainly explained by flowering patterns and yield related descriptors. The work has provided useful information on morphological characteristics of the farmer's potato to avoid duplication of resources and identify promising materials for future breeding program.

Keywords: diversity, Eritrea, morphological characterization, potato, principal component

1. Introduction

Potato cultivation has long history in Eritrea, however, little is known about their diversity. Understanding the genetic diversity of a species can assist in the analysis of the taxonomic structure of potential breeding populations for crop improvement (Afuape, Okocha, & Njoku, 2011). The correct identification of a cultivar can be used to certify its pureness as an accession (Rosa, de Campos, de Sousa, Sforça, Torres, & de Souza, 2010); although many cultivars share the same traits.

A number of methods are currently available for characterization including pedigree, morphology, agronomic performance, biochemical, and molecular (DNA-based) data (Mohammadi & Prasanna, 2003). The typical approach to variety identification involves the observation and recording of morphological characters or descriptors (Nováková, Šimáčková, Bárta, & Čurn, 2010). Morphological assessment is based on phenotypic characteristics of a plant species that determine diversity and similarity between and within populations. These descriptors are traits such as leaf type, tuber shape and flower colour which can be analyzed during different developmental stages of the crop. According to Fongod, Mih, & Nkwatoh (2012) morphological descriptors could be suitable for use in distinguishing accessions. Several studies using morphological descriptors have been conducted on potato (Ahmadizadeh & Felenji, 2011; Arslanoglu, Aytac, & Oner, 2011; Felenji, Aharizad, Afsharmanesh, & Ahmadizadeh, 2011) and other crops e.g. sweet potato (Afuape et al., 2011; Fongod, Mih & Nkwatoh, 2012; Tairo, Mneney, & Kullaya, 2008), chilli (Del, Perez, Alvarez, Arrazate, Damian, & Lomeli, 2007), peanut (Upadhyaya, Ortiz, Bramel, & Singh, 2003), or rice (Gana, Shaba, & Tsado, 2013; Sinha & Mishra, 2013).

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Genetic diversity assessment of farmers' and improved potato (*Solanum tuberosum*) cultivars from Eritrea using simple sequence repeat (SSR) markers

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Sixty three potato clones (51 farmers' and 12 varieties) from Eritrea, 18 and 12 varieties from Kenya and Rwanda, respectively were characterized using 12 highly polymorphic simple sequence repeat (SSR) markers. The study was designed to assess the genetic diversity and varietal distinctness among the different samples. In total, 91 alleles ranging between 2 (STM1053) to 13 (STM0031) alleles per marker were scored. All but 97.8 SSR markers were highly polymorphic with an average PIC value of 0.87 (0.51 to 0.98). All of the 51 farmers' cultivars were clearly distinct from each other. Samples from Eritrea showed the highest genetic diversity as explained by the diversity index (h). The principal coordinate analysis (PCoA) revealed that the local farmers' Eritrean samples are different from the Kenyan, Rwandese and even the imported varieties. Genetic distance analysis generated three clusters correlating with the PCoA findings. Cluster I consisted of 45 samples with 6 sub-clusters; Cluster II consisted of 29 samples with a majority (26) from Eritrea while cluster III consisted of 19 samples. Potato materials from Eritrea appeared to cluster separately from the other samples, which reflects a contribution from the Tuberosum germplasm prominent in temperate regions, unlike from the Andigenum germplasm for Kenyan and Rwandan potato materials. Most of the Eritrean samples in cluster I are farmers' cultivars with intermediate maturity, good performance and better tuber quality characteristics. Cluster II contains mainly the imported variety from Eritrea characterized by late emergence and late maturity. The Kenyan and Rwandese were grouped mainly in Cluster III. In summary, the farmers' cultivars are distinct from the Kenyan and Rwandese materials and represent more genetic diversity than the varieties imported into Eritrea. This finding is of interest to national breeding program to use the farmer's materials as source of genetic variation for traits of interest.

Key words: Potato, simple sequence repeat (SSR), principal coordinate analysis (PCoA), cluster analysis, Eritrea, multivariate.

INTRODUCTION

Potato *(Solanum tuberosum* L*)* is the fourth most important food crop in the world, after maize, wheat, and rice. The crop plays a significant role in human nutrition worldwide, where more than 320 million tons of potatoes