POTATO (*SOLANUM TUBEROSUM* L.) VARIETY DIVERSITY, ATTRIBUTES AND FARMERS' NEEDS IN ETHIOPIA

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Potato is commonly grown in low rainfall periods in Ethiopia and consequently crop yield is very low. New varieties with disease resistance have been released enabling them to be grown in the main rainy season and produce much higher yields. Nevertheless, the adoption of new varieties is not as high as expected. The majority of farmers still grow local varieties in the dry seasons. A series of experiments and activities were conducted to understand what traits farmers need as well as to document the distribution and importance of local Ethiopian varieties. A grower survey was conducted in six major potato production districts of Ethiopia during 2012 and 2014. At the same time, local varieties were collected from northwest and southern Ethiopia and characterized using molecular and morphological markers. Tubers of these varieties were tested and those found free of disease were multiplied in vitro and in the screenhouse for use in field trials. Nine local varieties and several new varieties were tested in two watering regimes (well-irrigated and stressed) under greenhouse conditions. A growers' participatory variety selection (PVS) experiment was also conducted in two districts in northwest Ethiopia during two production seasons (Meher and Belmehr).

The distribution of varieties differed among agroecologies, cropping systems and the extent to which farmers had access to external markets, as did the traits with which farmers are most concerned. Seventy to ninety percent of farmers reported growing two or more varieties. Our genetic fingerprinting and morphological characterization revealed that, of 44 local potato varieties

collected from major potato growing areas, only 15 are truly unique, the rest were found to be duplicates, known by different names. These unique Ethiopian local varieties harbor considerable genetic variation, comparable to that found in CIP, American and European clones. Some of the oldest Ethiopian clones appear to have descended from European germplasm. The water stress experiment shows that, in the Mesino season, no variety out-yielded the main local variety 'Siquare' under drought conditions. In the Belg season, 'Granola' and 'Abadamu' had the highest marketable tuber yields under both irrigated and stress conditions. Our results indicate potential for improving dry season potato production in Ethiopia by utilizing both selected local and new varieties. The growers' participatory experiment found that some local Ethiopian varieties yielded as well as or better than new varieties when using disease-free seed. Results further show that late-maturing varieties are, in general, well-adapted to Belmehr season while early-maturing ones with thick stems are well-adapted to Meher season. Overall, we found PVS to be an effective approach for identifying factors important for adoption of potato varieties. Based on these studies, we make several recommendations for those working to develop varieties suitable for farmers' and consumers' needs.

BIOGRAPHICAL SKETCH

The author grew up in a hardworking farming family in South Gondar, Ethiopia. He had a dream of supporting rural families with better crop production methods and improved soil conservation practices. After graduating high school in 1989, Semagn joined Haramaya University (then Alemaya University of Agriculture) to make his dream come true. He graduated with BSC degree in Plant Sciences in August 1993.

In 1994, the author was employed by Food for the Hungry International (FHI), a non-governmental organization in Ethiopia. After two years of service, he left FHI and was employed by Sheno Agricultural Research Center, Ethiopia. In September 2001, he joined the School of Graduate Studies, Haramaya University (then Alemaya University) and graduated with a MSC degree in Horticulture during 2003.

After his graduation, he worked as a researcher, department head and Center Director of Debre Birhan Agricultural Research Center. During 2009, he moved to Adet Agricultural Research Center to coordinate the Ethiopian potato research project. He was head of this project until he joined the Section of Horticulture, Cornell University, during the fall 2011 to pursue his PhD study.

Dedicated to my mother, Tiru Molla.

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CHAPTER 1: **INTRODUCTION**

Potato is the third most important food crop after rice and wheat in terms of global food consumption (FAO 2014). More than a billion people eat potatoes (Devaux et al. 2014). Because of its value for food security for a growing world population (FAO 2009), the past few decades have seen a dramatic increase in potato production and demand in many developing countries (FAO 2014). Potatoes can improve lives of poor families in developing countries by providing direct access to nutritious food, increasing household income and reducing their vulnerability to food price volatility (Devaux et al. 2014).

Potato is becoming an important food crop for improving the livelihoods of millions of smallholder farmers in the risk-prone highlands of sub-Saharan Africa, particularly in Ethiopia. The high yields, earliness of the crop and its excellent food value have the potential to improve food security, increase household income and reduce poverty in Ethiopia. As about 70% of the cultivated land of Ethiopia is suitable for potato production (Yilma 1987), it is undoubtedly an important food security crop for an increasing population. Indeed, potato production area has increased more than five fold from 30,000 ha during the 1970s (Kidane-Mariam 1979) to more than 179,000 ha today (CSA 2014). Since potatoes can produce more food per unit of water than many other major food crops (FAO 2009), it is the only food crop grown to any large extent in the dry seasons in Ethiopia. Potato growing seasons are shown in Fig 1-1. Belg, Belmehr and Mesino seasons are dry seasons.

Hirpa et al. (2010) divided major Ethiopia potato production areas into four subregions: Central, Eastern, Southern and Northwestern. The central subregion includes potato production areas within a 100-150 km radius of Addis Ababa. It includes West and North Shewa of Oromia and North Shewa of Amhara regions. The eastern sub-region covers the eastern highlands of Ethiopia, mainly East Harerghe. The southern sub-region includes areas in Southern Nations, Nationalities and Peoples regional State (SNNP) and some parts of the Oromia region. The major areas in this sub-region include East and West Arsi (Shashemene and surrounding areas), Guraghe, Gamo, Hadiya, Wolayita, Kambata, Silte and Sidama. The northwest sub-region covers West Amhara areas including south and north Gondar, East and West Gojjam and Awi. The Southern and northwest sub-regions represent over 70% of farmers who grow potatoes.

In spite of its value in food security and its expanding production area, the productivity of the Ethiopian potato crop is low, at 9 ton/ha (CSA 2014). Many factors contribute to the low yield, including drought (Doss et al. 2008; FAO 2010), frost, hail, pests, diseases (Bekele and Eshetu 2008), poor production practices and limited access to high quality seed (Gildemacher et al. 2009; Hirpa et al. 2010). Climate change is becoming a major threat to crop production in Ethiopia and other areas of sub-Saharan Africa (Conway and Schipper 2011). Climatic changes can differ locally and lead to different abiotic and biotic stresses on the potato crop. Climate-related hazards in Ethiopia include drought, floods, heavy rains, strong winds, frost, heat waves (high temperature) and lightning. Currently drought is the single most important climate-related hazard that periodically affects the country (FAO 2010). Ethiopia has experienced dry conditions 11 times in the last 55 years. Nowadays so-called ‘belg rain’ – the low rainfall events of February to April - is no longer dependable for potato production. In addition, late blight, bacterial wilt and viral diseases are expanding into areas that have previously been safe from them. Consequently, farmers are complaining that their potato yields are becoming lower and lower. If this problem continues, potato yields will decrease even further to the extent that potato production will become impossible.

To address the challenges and improve potato yields in the country, the identification of potato varieties suitable for Ethiopia was started in the early 1970s at Alemaya College of Agriculture (now known as Haramaya University). The process began by introducing and evaluating commercial varieties from Europe (Kidane-Mariam 1979). In 1975, a strategic and well-coordinated variety selection effort was established under the Institute of Agricultural Research (IAR), now known as the Ethiopian Institute of Agricultural Research (EIAR). The first official variety was released in 1987 by Haramaya University. Today, the Ethiopian agricultural research system, including federal and regional research institutes as well as universities, are working to address many potato production problems by releasing new varieties. So far 31 potato varieties have been officially released for production (MOA 2013), by selecting among advanced clones, tuber families and true potato seeds imported from the International Potato Center. High yield and resistance to late blight are the main traits emphasized during variety selection in the country (Woldegiorgis 2013).

Although these new varieties are grown in some parts of the country (Woldegiorgis et al. 2013), their adoption by farmers in most potato production areas is low (Abebe et al. 2013; Woldegiorgis 2013) so that only a limited number of the new varieties are grown (Woldegiorgis 2013). The majority of smallholder farmers still grow older ‘local’ varieties (Yazie et al. 2009; Labarta et al. 2011; Hirpa et al. 2010). According to Abebe et al. (2013) demand for local varieties is higher than for new varieties because of better stew quality and easier crop management. This raises two major questions: what are the merits of local varieties, and where are they grown in the country? Why have the new varieties not been adopted by most farmers as expected?

Tremendous variation in altitude, temperature, rainfall, soil type, and ecological settings gives rise to the need for a wide range of varieties and this, in turn, has challenged the national research program as it seeks to develop new varieties. Nevertheless, because potato has been grown in Ethiopia for more than 150 years, current local varieties may meet some high-priority needs. Few studies have sought to document local cultivars in the country (Yazie et al. 2009; Tesfaye et al. 2008; Labarta et al. 2011). Tesfaye et al. (2008) and Labarta et al. (2011) reported 22 and 14 local varieties, respectively, all known only by local names. Within the national research system, local varieties are generally considered to be low yielding and susceptible to late blight. They have been described as having a narrow genetic base for improvement (Kidane-Mariam 1979), with lower yield potential and lower disease and pest resistance (Kidane-Mariam 1979; Lemaga 1982). Because of this perception, local varieties have received little attention in potato variety development in Ethiopia. There is insufficient information on their origin, potential benefits, limitations, and areas of adaptation for these cultivars (Woldegiorgis et al. 2008). Whether different local names given to local varieties refer to the same or different genotypes is also not known. In general, available potato genetic resources in Ethiopia have not been well assessed and conservation measures are yet not in place.

As Williams et al. (1991) noted, the first step in crop improvement in developing countries should be a full assessment of the local material. That is, whether local cultivars have considerable variation or not in relation to key traits, such as response to water stress, as well as local adaptation. Of particular relevance to Ethiopia, given looming climate change, is whether local varieties have the potential for selecting among, or breeding from, for the purpose of identifying clones with drought tolerance.

A second issue is understanding why new varieties have not been well adopted in many potato growing areas of the country. Understanding what farmers need in potato varieties and factors that determine potato genetic diversity can play an important role not only for the improvement of the crop but also for conservation purposes. Three major factors may account for the limited acceptance of new varieties. i) There may be a mismatch between potato breeders' objectives and the farmers' preferences and needs (VomBrocke et al. 2010). ii) Evaluation of subjective traits such as taste, culinary qualities, and color is a difficult challenge for breeders operating without close collaboration with farmers and social scientists (Almekinders and Elings 2001; Bellon 2002). iii) Potato is a semi-perishable vegetable but storability varies between varieties, environment and agronomic practices, and storage properties under different conditions may not be evaluated by breeders.

Looking at the two major potato production areas, the northwest and south, the research presented in this thesis sought to: i) assess potato genetic resources in the country and ii) investigate the needs of farmers in potato variety selection, using a series of independent studies. Chapter 2 reports the results of a survey that was conducted in six different agroecologies of Ethiopia, which collectively represent major potato growing areas and vary in terms of access to national markets. It details why potato varieties are adopted, maintained or lost at the household level, and documents the number of varieties grown at the household level, as well as the distribution of major varieties in major potato growing areas. Chapter 3 reports on the use of molecular markers to assess genetic relationships among Ethiopian potato cultivars and their relationship to varieties developed elsewhere. Chapter 4 reports on a study of drought stress tolerance, comparing selected Ethiopian local varieties with selected varieties from the International Potato Center and Europe. This experiment was conducted over two growing seasons in northwest Ethiopia. Chapter 5 reports on a participatory variety selection (PVS) approach to investigate what traits farmers' are most concerned with, across gender and differences in agroecology

This study is the first in Ethiopia to answer basic questions about potato that are keys to its future improvement. Each of the chapters are interrelated. This study documents unique potato genotypes as well as their distribution, and their relationship to potatoes developed elsewhere. It also identifies key traits and aspects of agroecology, cropping systems and market access that need to be considered if new varieties are to be adopted. The Ethiopian research program can utilize this information to select parents for future breeding, focus variety development on traits needed for acceptance, and guide conservation activities.

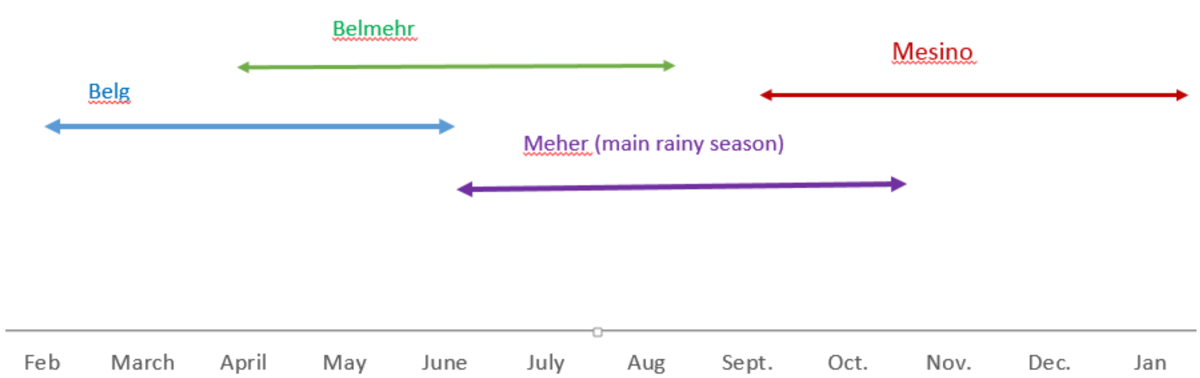

Figure 1-1 Potato growing seasons in Ethiopia

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CHAPTER 2: **POTATO VARIETY DIVERSITY, DETERMINANTS AND IMPLICATIONS FOR POTATO BREEDING STRATEGY IN ETHIOPIA**

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Abstract

Understanding what farmers need in potato varieties and assessing available genetic resources at the farmer and district levels is important for the conservation and improvement of potato in Ethiopia. A survey was conducted in six major potato growing districts representing different agro-ecologies, cropping systems, market outlets, and levels of new variety adoption. Seventy to ninety percent of the farmers surveyed reported growing two or more potato varieties; some farmers reported growing up to five. The greatest diversity at the district level (up to 10 potato varieties) was recorded at Gumer & Geta where there is better access to new varieties while the lowest diversity was reported in districts with low access to new cultivars. The distribution of varieties differed among agro-ecologies as did the traits that farmers were most concerned with, such as drought tolerance, late blight resistance, yield potential, marketability, food value, storage quality, adaptation to low soil fertility, time to maturity and suitability for multiple harvesting. Farmers' decision-making processes and external factors that influence potato variety diversity were also documented. The registration of predominant local varieties and use of these local varieties as a starting point for the development of improved varieties are some of the recommendations for future potato breeding in Ethiopia. Moreover, it is necessary to consider variations in agro-

ecologies, cropping systems and market outlets in the process of developing varieties suitable for farmers' and consumers' real needs.

2.1 Introduction

The potato holds great promise for improving the livelihoods of millions of smallholder farmers in the highlands of Ethiopia. The potential for high yield, early maturity, and excellent food value give the potato great potential for improving food security, increasing household income, and reducing poverty (Woldegiorgis et al. 2008). The crop's genotypic variation and relatively short vegetative period allows farmers to find an appropriate season for its cultivation under a wide range of weather patterns and less predictable climates. As a result, the combined area planted to potato in Ethiopia for both Belg (short rainy season - February to May) and Meher (long rainy season - from June to October) growing seasons is about 179,000 hectares (CSA 2014). In spite of its popularity, the productivity of the crop is relatively low, at about 9 ton/ha (CSA 2014). Yields are typically three to five times higher in developed nations (Struik and Wiersema 1999). Many factors contribute to the low yield, including drought (Doss et al. 2008; FAO 2010), frost, hail, pests, diseases (Bekele and Eshetu 2008), poor production practices and limited access to high quality seed (Gildemacher et al. 2009; Hirpa et al. 2010).

The Ethiopian potato research system has released 31 new potato varieties to address some of these production problems (MOA 2013). All of these varieties originated outside Ethiopia, mainly from the International Potato Center (CIP). The breeding strategy targets high and stable yield with a good level of horizontal resistance for late blight (Woldegiorgis 2013). Although these new varieties are grown in some parts of the country (Woldegiorgis et al. 2013), their adoption by farmers in most potato production areas is low (Abebe et al. 2013; Woldegiorgis 2013) so that only a limited number of them are grown (Woldegiorgis 2013). Hence, the majority of smallholder farmers still grow old varieties (Gildemacher et al. 2009; Hirpa et al. 2010).

Maintaining on-farm variety diversity is one of the strategies that small farmers adopt to mitigate risks associated with crop production in heterogeneous environments characterized by varying soil quality, temperature, rainfall, topography, etc. (Lando and Mak 1994; Bellon 1996b). Indeed, farmers in different parts of the country grow two or more varieties in the same growing season (Garuma et al. 2013; Tesfaye et al. 2013). According to Bellon (1996b) the choice of small farmers to grow a diverse set of varieties reflects their desire to address concerns including drought, eating quality and storability. Abay et al. (2008) also reported that managing a diverse set of varieties helps farmers to keep their options open and reduce the risk of crop failure. Growing diverse crop varieties is also recognized as an important adaptation strategy for a changing climate (Wolfe 2013).

Ethiopia's tremendous variation in altitude, temperature, rainfall, soil type, and ecological settings gives rise to the need for a wide range of varieties, which are not likely to be provided by existing breeding programs (Cavatassi et al. 2011). Since potato is grown from mid altitudes to very high mountaintops, and from humid to dry areas in the country, improvements in productivity will require varieties to be developed that are collectively adapted to this wide range of environments. Ethiopia is neither the center of origin nor the center of diversity for potato. However, the crop has been cultivated for more than 150 years in the country. Hence, the available set of local varieties has been developed through a constant process of farmer experimentation, evaluation and selection of introduced varieties or clones from outside sources. We will refer to varieties previously selected by farmers as "local varieties"; while varieties developed by the research system over the past 28 years since their first release in 1987 will be referred to as "new varieties". The fate of both local and new varieties is determined by the decisions that farmers make. Jarvis and Hodgkin (1999) noted that decisions made by farmers in the process of planting, managing and harvesting of crops affect crop genetic diversity; these decisions in turn are influenced by a complex set of environmental and socio-economic factors.

Despite the importance and widespread production of potato in the country, few studies have sought to document Ethiopia's potato genetic resources and understand the practices farmers use to manage genetic diversity. A survey conducted by the Holetta Agricultural Research Center documented 29 potato varieties, of unknown origin, that are identified with local names (Tesfaye et al. 2008). However, it was unclear whether any given local name always referred to the same clone, or whether any given clone was always known by the same local name (Woldegiorgis et al. 2008). Two other studies have also cataloged some of the varieties grown in Ethiopia: Yazie et al. (2009) surveyed a potato production system in northwest Ethiopia while Labarta et al. (2012) studied adoption of new potato varieties. Each found that both local and new varieties were being grown.

This paper seeks to further document and understand the reasons why potato varieties are adopted, maintained, or lost at the household level in Ethiopia. Based on interviews and discussions with farmers, we sought to: i) assess the potato variety diversity at the household level, ii) analyze the spatial distribution of these genetic resources at the district level, iii) evaluate the perceived merits of currently available potato genetic resources in order to provide documentation for further breeding and conservation work, iv) document farmers' potato variety selection concerns across agro-ecologies, and v) understand farmers local seed management practices that contribute to variety diversity.

2.2 Materials and Methods

2.2.1 Description of the study sites

The survey was conducted in the Shashemene, Gumer and Geta, Banja, Laigaint, Yilmana and Quarit districts that collectively represent different agro-ecologies, cropping systems, access to new varieties and market outlets. Descriptions of survey districts and their agro-ecological designations are given in Table 2-1. Shashemene, located in East Arsi and 250 km from Addis Ababa, is a hub of seed and ware potato markets (Emana and Nigussie 2011). In Shashemene most potatoes are grown for sale as tablestock; in Gumer and Geta most farmers grow potatoes to sell as seed; in the four other districts most potatoes are grown for the family's own consumption, which is typical for most of the country. The Kebeles (lowest administrative units) we surveyed in this district are all within 10 km of the city of Shashemene. Yilmana, a district 42 km east of Bahir Dar, is a major source of ware potatoes for the city of Bahir Dar. Quarit, a neighboring district of Yilmana, has poor road infrastructure and thus no easy access to new varieties. Laigaint, a district in South Gondar, represents a dry and cool highland with moderate access to new varieties through non-governmental and governmental organizations. Farmers of this district often experience drought and subsequent crop failure. Banja, a district in the Awi Administrative Zone and 100 km from Bahir Dar, represents sub-humid agro-ecology with low access to new varieties. The greatest access to new varieties is represented by the Gumer and Geta districts, both in the Gurage zone. CIP and Ethiopian Institute of Agricultural Research (EIAR), in close coordination with district agriculture department offices, have been working together to disseminate potato varieties and associated technologies since 2008 (Woldegiorgis et al. 2013). Since Gumer and Geta have similar agro-ecologies and social conditions we treated them as one district. The locations of the study districts are shown in Fig 2-1.

2.2.2 Methods of data collection

This survey was conducted during 2012, except for Gumer and Geta. Gumer and Geta were added in 2014 to incorporate districts that have made intensive efforts to introduce new varieties. The survey design consisted of two stages; in the first stage, districts were selected using farming system data from the Central Statistical Authority (CSA 2012; CSA 2013) and by consulting researchers at Adet and Hawassa Agricultural Research Centers (ARC) as well as crop extension experts from the Amhara Bureau of Agriculture. Potato-growing districts were selected to represent a diversity of agro-ecologies, varying levels of new variety adoption, and different degrees of access to outside markets. In the second stage, two Kebeles (the smallest administrative unit in Ethiopia; each containing about 500 families) were selected in each district, except in Yilmana and Quarit where one Kebele was selected for each because these districts are neighbors and represent the same moist agro-ecology. Primary data were collected through direct observations of local markets, farmers' potato fields and storage structures, conducting semi-structured interviews with farmers, and discussions with farmer focus groups. Checklists for semi-structured interviews were developed based on the information from direct observations and focus group discussions.

For direct observation of farmers' potato fields, storage structures and markets, a team comprised of plant breeders and a socio-economist, together with agriculture development agents, undertook a transect walk in each of these Kebeles. During each visit, information was gathered on the performance of the potato crop in the field, including disease status, management practices, varieties grown and area allocated for the crop. At least two farmers' storage practices were also visited per Kebele and data such as the type of storage structure, the varieties stored and seed tuber quality in the storage were collected. The team also visited local potato markets at the district level to collect names of potato varieties, price differences between varieties and source of the produce. Major potato markets in Addis Ababa, Shashemene, Hawassa and Bahir Dar were also surveyed for the same purpose. These major markets were selected because they are potato market hubs in the country (Emana and Nigussie 2011) and some of them (Bahir Dar, Shashemene and Hawassa) are close to the survey sites. From these major cities, at least three main produce stores each from wholesalers and retailers were visited and traders were interviewed about the varieties, price differences and produce sources.

Focus group discussions had at least 10 participants, including development agents and prominent elders of both sexes. The selection of these groups was based on consultation with development agents and local administrators working in each of the Kebeles. Issues such as the cropping seasons and their related planting and harvesting dates, limiting problems for each cropping season, major varieties and their merits, advantages and disadvantages of intercropping, market outlets, and seed sources were addressed in each focus group discussion.

For the semi-structured interviews data collectors, together with development agents, went to randomly selected 'Gots' in each Kebele. Gots are the residential areas within a Kebele; a Got typically contains about five to twenty dwellings. For each Got visited, we interviewed every household where the farmer was home that day, and continued visiting Gots until 20 households had been surveyed per Kebele (in 2012) or 40 households had been surveyed (2014). All of the interviewed farmers had experience with potato production. Information collected included how many varieties are grown per season, whether two crops are grown each year, area allocated and

Table 2-1: Survey area information

Regional state	District	Elevation (meters)	*Agro-ecology	**Cropping Season	Planting dates	***Seed source	Major production constraints
Amhara	Quarit	3050	Moist cool highland	Belmehr	March- April	Belmehr seed	hail damage, drought
				Mesino	August- Sept	Seed from Sekela area	drought
				Belg (Irrigation)	January	Belmehr seed	
	Yilmana	2500	Moist mid highland	Belmehr	March- April	Belmehr seed	bacterial wilt, late blight, drought
				Belg (Irrigation)	January	Belmehr seed	
	Banja	2560	Sub-humid cool highland	Belmehr	March- April	Belmehr & Mesino produce	hail, bacterial wilt and late blight
				Mesino	September	Belg produce	
				Belg	December	Belmehr produce	drought
	Laigaint	3120	Sub-moist (dry) cool highland	Belmehr	March- May	Belmehr produce	drought, hail damage
				Belg (Irrigation)	December	Irrigation produce	
Oromia	Shashemene	1915-2027	Sub-moist mid high land, bimodal rainfall	Meher	July	Belg produce	drought, bacterial wilt and late blight
				Belg	February-March	Meher produce	
South	Gumer & Geta	2800- 2850	Moist cool highlands with bimodal rainfall	Meher	July	Belg produce	late blight
				Belg	December-January	Meher and Belg seed	drought some years

*Based on MOA (2000) agro-ecology classification system in Ethiopia.

**Potato can be grown during the primary rainy season (Meher), the small rainy season (Belg), Belmehr season (the cropping season which combines Belg and Meher seasons), the Mesino season (the cropping season for residual potato production immediately following the main rainy season) or at a time of the farmers' choosing when irrigation is available. ***The seed source for the specific cropping season is the last harvest of the respective cropping season in the same area.

seed sources for each variety, utilization of chemical fertilizers and fungicides, and intercropping and storage practices.

2.2.3 Variety identity confirmation

To establish whether a variety with a given name grown in one district is similar or different across districts, or within a district, a sample of every variety grown in each district was collected from either markets or farmers' fields, and planted in a screen house at the Adet Agricultural Research Center for genetic fingerprinting. Ten to twenty five tubers were collected from each of the local varieties identified by growers, traders or marketers. Varieties were genotyped with 8303 SNPs, using the potato Illumina Infinium array developed by the SolCAP project (Hirsch et al. 2013). Varieties that shared genotype calls at 99% or more of the SNP loci were deemed identical.

2.2.4 Statistical analysis

A list of farmers' selection criteria was compiled from answers given by focus group discussion participants when asked about the positive and negative attributes of each variety in each Kebele. Farmers were asked to rank their varieties against each of these selection criteria during our semi-structured interview. To evaluate the relationship of major varieties with farmers' variety selection criteria, Spearman rank correlation was computed at country level based on the procedure outlined by Sokal and Rolf (1981) and performed using JMP software (SAS Institute, 2012, JMP PRO 10.0.2). The farm area allocated to each variety per interviewed household (in units of "Timad") were summed for each district and converted into percentages. Descriptive statistics and frequencies were also calculated for the proportion of farmers who grow a diverse set of varieties (1-4 varieties), the proportion of farmers involved in different production practices, as well as seed sources and storage types across the districts. Although the data from Gumer & Geta were collected 2 years later than the rest of the locations, we compiled and analyzed the data of all districts together because the multiplication rate of potato is very slow and hence a minimal amount of seed was introduced to Gumer & Geta from outside sources during those two years.

The Map Created by: Disaster Prevention and Preparedness Commission (DPPC) Information Centre UN OCHA-Ethiopia

Figure 2-1: Survey sites across major potato growing districts during 2012 and 2014

2.3 Results

2.3.1 Major varieties and their distribution across districts

The major varieties grown in each district are summarized in Table 2-2. In each district, there are at least three widely grown varieties differing in attributes like time to maturity, cooking and storage qualities, and market value. The highest number of varieties was recorded at Gumer & Geta (ten varieties, five new ones) while the lowest was in Quarit (three varieties, no new variety).

The farmer variety ‘Siquare’ is widely grown in all four districts of the Amhara region and occupied 24% of the acreage planted to potato. It was widely grown in Quarit (58%), Yilmana (39%), Banja (56%) and Laigaint (14%). ‘Abalo’ is the second most widely grown farmer variety in the cool highlands of the Amhara region (Laigaint, Quarit and Yilamana). ‘Samune’ is another farmer variety and widely grown in the Banja district of the Amhara region. ‘Abateneh’ (in Quarit) is grown by some farmers and it is widely adopted in Sekela, a neighboring district outside the survey area.

In Shashemene, ‘Agazer’ and ‘Nech Ababa’ are the two dominant local varieties and cover 70% and 23% of the total sampled potato acreage, respectively. All the farmers in Shashemene reported growing ‘Agazer’. It is the leading variety in terms of average area planted per farmer, at 0.43 hectare. It has high local market demand and has become the most widely sold variety in national markets, replacing ‘Nech Abeba’, which is also grown in the same district. Some farmers also grow ‘Key Dinch’ and ‘Jibut’.

In Gumer & Geta, although the new varieties ‘Gudene’ and ‘Jalene’ are the most widely grown, some local varieties are still important. A farmer variety that is variously called ‘Hosana’, ‘Holland’, and ‘Key Dinch’ covers about 13% of the total potato acreage in the districts. Additional local varieties, including ‘Ajamazer’, ‘Nazret’, ‘Key Tolch’, ‘Asefu’ and ‘Askot’ are also grown by some farmers in Gumer & Geta.

The distribution and level of production of new varieties differed across study districts (Table 2-2). New varieties occupy a large share of the total potato acreage in the Gumer & Geta (78%) and Yilmana (43%) districts. ‘Gudene’ and ‘Jalene’ are widely grown by farmers in Gumer & Geta while ‘Sisay’ is widely grown in Yilmana. Of the sampled potato farms in Gumer & Geta, ‘Gudene’ covers about 42% of the total potato acreage followed by ‘Jalene’ (32%) and local varieties (21%). New varieties had been disseminated to Shasehemene, Laigaint and Baja districts at various times in the past but they had not yet been widely adopted. None of the farmers surveyed in Quarit had ever received seed of any new variety.

2.3.2 Variety diversity at farm level

The number of varieties grown per household in each district is shown in Fig 2-2. In all of the districts surveyed, at least 70% of the farmers grew two or more potato varieties at the same time in the same growing season. The number of varieties grown by each household differed among districts. In districts with better access to new varieties (based on the number of farmers who planted the new varieties), such as Gumer & Geta and Yilmana, 84% and 50% of the farmers, respectively, grew three or more different varieties for different purposes in the same growing season while at Quarit and Banja, the percentage of farmers who grew three varieties was approximately 10% and 5%, respectively. About 37% of the farmers in Gumer & Geta grew four or more varieties while more than 25% of the farmers in Laigaint, Quarit and Shashemene grew only one variety.

During the group discussions, we asked farmers why they grew multiple varieties at the same time. One answer was that varieties mature at different times, thus planting multiple varieties expanded the time window when they would have food, which is important as there are occasionally regional food shortages. In each of the districts farmers plant early maturing and late maturing varieties, where the late maturing varieties are planted early and the early ones are planted late. A second answer was that they grow different types of varieties for different purposes; some are grown for

Table 2-2: Predominant potato varieties grown by farmers in different regions of Ethiopia

Common name	Origin	**District (**percent of total potato acreage planted to varieties)					
		Shasehemene	**Quarit**	**Yilmana**	**Laigaint**	**Banja**	**Gumer & Geta**
Agazer	local variety	69.8	-	-	-	-	-
Nech Abeba	"	22.9	-	-	-	-	-
Key Dinch	"	1.8	-	-	-	-	-
Jibut	"	1.9	-	-	-	-	-
Abalo	"	-	40.3	17.2	72.2	-	-
Siquare	"	-	58.3	39.5	14.5	56.1	-
Samune	“	-	-	-	-	41.8	-
Abateneh	“	-	1.4	-	-	-	-
Hosana/Holland	“	-	-	-	-	-	12.6
Ajamazer	“	-	-	-	-	-	3.4
Nazret	“	-	-	-	-	-	2.3
Key Tolch	“	-	-	-	-	-	1.3
Asefu	“	-	-	-	-	-	1.1
Askot	“	-	-	-		-	0.01
Others	“	-	-	-	0.1	0.1	1.4
Local variety Total		**96.4**	**100.0**	**56.7**	**86.8**	**97.8**	**22.2**
Sisay	new variety	-	-	33.7	-	-	-
Jalene	“	2.1	-	-	5.2	-	31.6
Gudene	"	1.5	-	-	1.0	-	41.5
Belete	"	-	-	3.2	7.0	-	4.2
Tolcha	"	-	-	-	-	1.1	-
Gera	"	-	-	6.4	-	-	0.1
Guasa	"	-	-	-	-	1.1	0.4
New variety Total		**3.6**	**-**	**43.3**	**13.2**	**2.2**	**77.9**

(-) denotes “not reported to be present” their own food consumption and others are grown for seed and ware potato markets. ‘Abalo’ is grown mostly for household consumption at Laigaint and Quarit, while ‘Sisay’ is mainly grown for distant markets in Yilmana. In Gumer & Geta, ‘Gudene’ is grown for distant markets and as food in the dry season while ‘Hosana’ is grown mainly for immediate food consumption after harvest. A third reason was that planting multiple varieties helps to avoid risk in case one variety is destroyed by disease or other natural factors such as drought, hail damage, etc. Some varieties are relatively tolerant to moderate drought (e.g., ‘Abalo and ‘Abadamu’, the latter a local variety grown by some farmers in cool highlands outside the study Kebeles) while others are resistant to late blight (‘Siquare’, ‘Agazer’, ‘Sisay’ and ‘Gudene’) and hail damage (‘Abateneh’, ‘Tolcha’ and ‘Belete’).

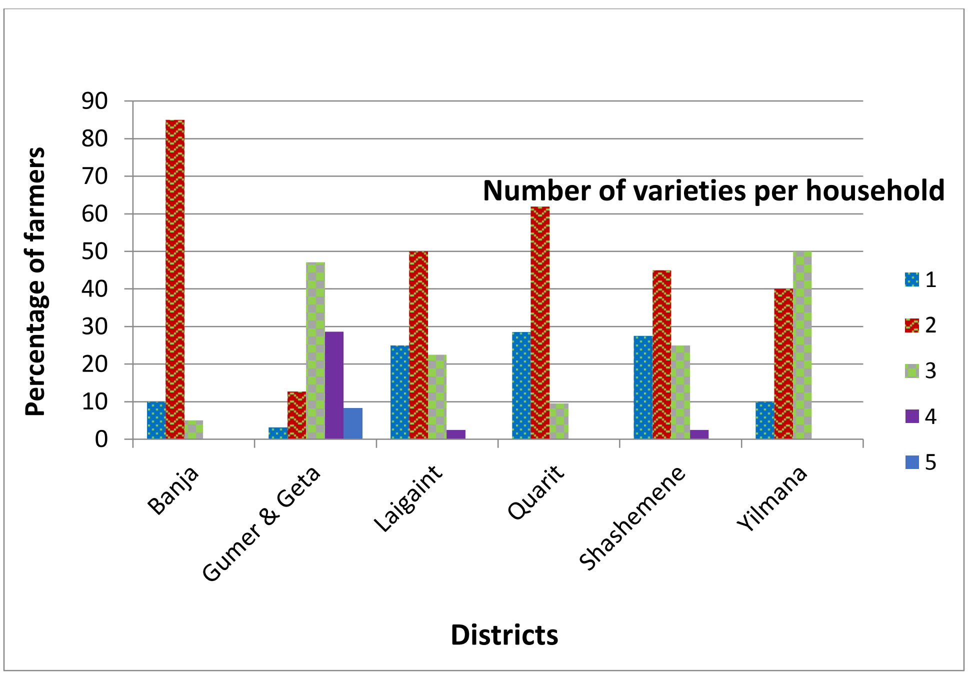

Figure 2-2: Number of varieties grown per household in the study districts expressed in percentage of farmers

2.3.3 Farmer perceptions that guide choice of potato varieties in different agro-ecologies

Farmers can choose among varieties to help address production challenges (some constraints are summarized in Table 2-1) and to meet different purposes (Tables 2-3, 2-4). As summarized in Table 2-3, in each district, farmers have varieties that they can grow for a wide range of purposes. Based on our focus group discussions, high yield, late blight resistance, storability, drought tolerance, suitability for boiling, early maturity and market-desired tuber size are major and common variety selection traits for most of the surveyed districts. Some variety selection traits are district-specific, such as suitability for multiple harvesting (in Laigaint) and adaptation to low soil fertility (mainly in Laigaint, Quarit and Banja districts). Table 2-4 shows how farmers' perception of each variety relates (Spearman rank correlation) to various traits.

Drought is the major production problem in the Belg season for Shashemene and Gumer & Geta and in the Belmehr season for Amhara region even though the degree of severity is higher in the later. Farmers learn which clones are tolerant to drought by observing variety performance during drought years. When there is consistent early onset of rainfall (such as in Laigaint, Quarit and the cool highlands of Yilmana), late maturing varieties can be grown. These varieties are better than others in tolerating moderate late onset drought. Varieties such as 'Abalo', 'Agazer' and 'Gudene' received a significantly higher ranking in their response to drought. Moreover, based on our focus group discussion, 'Abadamu' has some tolerance level to drought. Early maturing varieties such as 'Agazer', 'Siquare' and 'Ajamazer' are able to escape early onset droughts by planting them late in the season during the Belg or Belmehr seasons. Note also that early maturity is an important trait in Shashemene area because it enables the farmers to grow two crops per year.

Table 2-3: Specific characteristics of different potato varieties grown across six districts based on farmers' perception*

Traits	Shashemene	Quarit	Yilmana	Laigaint	Banja	Gumer & Geta
Drought tolerance	Agazer	Abalo, Abadamu	-	Abalo,	-	Gudene
Adaptation to low soil fertility	-	Abalo	-	Abalo	Samune	-
Hail damage	-	Abateneh	-	Belete	Tolcha	-
Late blight resistance	Agazer, Key Dinch, Jibut	Abateneh, Siquare	Siquare, Sisay, Belete	Siquare, Belete	Siquare	Gudene, Belete
High yielding	Agazer, Nech Abeba	Abateneh	Sisay, Belete	Belete	-	Gudene, Belete, Jalene
Storage quality	Agazer	Abalo, Abateneh, Siquare	Abalo, Sisay, Siquare	Abalo, Siquare	Siquare	Gudene
Early maturity	Key Dinch, Agazer	Siquare	Siquare	Siquare	Siquare	Ajamazer, Jalene
Long dormancy	-	Abalo, Siquare	Siquare	Abalo, Siquare	Samune	Gudene, Nazret
Short dormancy	Nech Abeba	-	-	-	-	Hosana
Multiple harvesting	-	-	-	Abalo	-	
Tasty when boiled	Agazer	Abalo	Abalo	Abalo	Samune	Hosanna
Market demand	Agazer, Nech Abeba	Siquare	Sisay, Siquare	Siquare	Samune, Siquare	Gudene
Early planting	-	Abateneh, Abalo	Siquare	Abalo, Siquare	-	
Late planting	-	Siquare	Gera, Belete	Siquare, Belete, Jalene	-	

*Compiled from the farmers' rating of different traits, from focus group discussions, and from market and field assessment.

Variety storability, both in storage structures or in-field, is a very important trait in our survey areas. Long storage varieties are required in districts in the Amhara region and Gumer & Geta, while short storage varieties are needed for the Shashemene area. Interestingly, all of the varieties that ranked highly for drought tolerance also ranked highest in storage quality. Some varieties in the Amhara region such as ‘Siquare’, ‘Abateneh’ and ‘Sisay’ also have a moderate degree of storability both in-field and in storage structures. In contrast, varieties from the south such as ‘Nech Abeba’, ‘Hosana’ and ‘Nazret’ have very short storability both in storage structures and in-field storage.

Resistance to late blight is another important trait that determines the acceptance of a variety. Farmers are forced to plant susceptible varieties in the dry season (Bekele and Eshetu 2008), when rainfall is not dependable. The Spearman rank correlation showed that farmers perceive ‘Gudene’, ‘Agazer’ and ‘Key Dinch’ to have higher late blight resistance (Table 2-4). ‘Gudene’ and ‘Agazer’ are grown in both the Belg and Meher seasons, because of their better late blight resistance. Based on focus group discussion, the varieties ‘Sisay’, ‘Belete’, ‘Abateneh’, ‘Siquare’, and ‘Jibut’ also appear to have some degree of tolerance to the disease. Most local varieties (e.g; ‘Abalo’, ‘Asefu’, ‘Askot’, ‘Hosana’ and ‘Nazret’) are very susceptible to late blight. Our data further revealed that most of the new varieties and major local varieties in Shashemene (‘Agazer’ and ‘Nech Abeba’) are perceived to have higher yield (Table 2-4).

Traits demanded by the market are important factors for variety adoption in Shashemene and Yilmana because these districts are hubs for national and regional markets, respectively. ‘Agazer’, ‘Nech Abeba’, ‘Siquare’ and ‘Sisay’ (particularly in Yilmana) produce relatively large tubers and dominate market sales in the country. Resistance to bruising (good for transportation), resistance to tuber disintegration during cooking, and acceptable stew quality for consumers are among the qualities of good marketing varieties mentioned by farmers. Color is a major factor in the Shashemene district but not in districts in the Amhara region. The central market (Addis and neighboring cities) prefers white skin varieties and thus, unsurprisingly, more than 98 percent of Shashemene farmland was planted with white skin varieties. Even so, local markets in Shashemene and Hawassa still accept purple skin potatoes (e.g., ‘Bule Local’), although ‘Bule Local’ is mainly grown outside of the Shashemene area. Although ‘Hosana’ (also known as ‘Key Dinch’ or ‘Holland’) is low yielding, has poor storage quality and is susceptible to late blight and other abiotic and biotic stresses as indicated in Table 2-3, most farmers in Gumer & Geta want to grow this variety during the Belg season because it has better taste and flavor than the other varieties grown in these districts.

Potatoes in Ethiopia are mainly consumed boiled or in stew. To be accepted, varieties should be suitable for at least one of these purposes. For districts specializing in market production, a variety may be acceptable even if it is not suitable for boiling. ‘Sisay’ is an example; it cannot be used for boiling (because of a detectable bitter taste), but is acceptable for stew. A good stew potato remains firm, does not disintegrate when boiled, and absorbs fat/oil from the stew. For their own consumption, farmers prefer varieties suitable for both boiling and stew. Based on the rank correlation and focus group discussions, only local varieties, and none of the new varieties, are perceived to have good “taste of boiled potato”. Most of the new varieties except ‘Jalene’ are negatively correlated with “taste of boiled potato”. ‘Abalo’, ‘Aagzer’ and ‘Hosana’ have the highest significant correlations to “taste of boiled potato”.

Table 2-4: Spearman rank correlation between predominant varieties grown in different districts of Ethiopia and traits that farmers state are important to them

Variety	Origin	Big Tubers	High Yield	Early Maturity	Taste of boiled potato	Storage Quality	LB Resistance	Drought Tolerance
Abalo	Farmer	-0.097**	0.032	-0.347**	0.227**	0.287**	-0.167**	0.095*
Siquare	"	0.079*	0.037	0.149**	0.061	0.062	-0.027	-0.110**
Agazer	"	0.106*	0.162**	0.219**	0.261**	0.182**	0.167**	0.196*
Jibut	"	0.065	0.011	0.017	0.010	0.005	0.014	-0.011
Nech Abeba	"	0.095*	0.118*	-0.007	0.018	-0.080*	0.068	0.012
Key Dinch	"	0.031	-0.024	0.089*	0.069	0.069	0.076*	0.061
Ajamazer	"	-0.192**	-0.153**	0.143**	-0.113**	0.021	-0.008	-0.001
Asefu	"	-0.138**	-0.155**	-0.047	-0.015	-0.132**	-0.133**	-0.149**
Askot	"	-0.086*	-0.066	-0.017	-0.091*	-0.057	-0.079*	-0.052
Hosana	"	-0.443**	-0.437**	0.014	0.199**	-0.434**	-0.311**	-0.284**
Nazret	"	-0.280**	-0.256**	-0.173**	-0.261**	-0.153**	-0.215**	-0.239**
Key Tolch	"	0.074*	-0.002	-0.134**	-0.157**	-0.045	0.004	0.010
Belete	New	0.136**	0.164**	-0.066	-0.077*	-0.029	0.055	0.054
Jalene	"	0.166**	0.156**	0.249**	0.039	-0.269**	0.005	-0.077*
Gudene	"	0.364*	0.273**	-0.110**	-0.220**	0.497**	0.451**	0.414**
Guasa	"	-0.006	0.003	-0.074*	-0.082*	-0.082*	-0.064	-0.070

*Significant at 5% probability level
** Significant at 1% probability level

Farmers from Laigaint, Quarit and the highlands of Yilmana prefer ‘Abalo’ for food, drought tolerance, long dormancy, adaptation to low soil fertility, suitability for long in-field storage, and for multiple harvesting (at least two harvesting dates in the crop growing season) (Table 2-3). However, due to its susceptibility to late blight (as shown in Table 2-4), the production of ‘Abalo’ is limited to cool highlands where late blight pressure is low. Although the production of ‘Abalo’ is limited to the Belmehr season (a cropping season that starts in the dry season but ends in the main rainy season), it reaches maturity in August (main rainy season). However, in the lower elevation areas, high relative humidity coupled with high temperature creates favorable conditions for late blight infection starting from July. The farmers in the Amhara region prefer ‘Siquare’ for both market sales and earliness (allowing late planting) and better late blight resistance than ‘Abalo’. ‘Abateneh’ (in Quarit) exhibits high yield, desirable tuber size and shape, and moderate resistance to late blight but is prone to tuber disintegration when cooked.

Farmers in Shashemene prefer ‘Agazer’ for late blight resistance, high yield, early maturity and good market and food value. They also prefer ‘Key Dinch’ for early maturity, although because of its colored skin, it has less market value. ‘Nech Abeba’ is also preferred by many farmers in the district for short storage dormancy (allowing rapid replanting after harvest), high yield, and for its market value due to its attractive white color. However, it is very susceptible to late onset drought during the Belg season and to late blight compared to ‘Agazer’.

New varieties are grown by many farmers, especially in Gumer & Geta and Yilmana, for their high yield, late blight resistance (most varieties) and other attributes. In Gumer & Geta, ‘Gudene’ is preferred for its stress tolerance (drought, heavy rainfall load during main rainy season, late blight resistance), high yield, better storability in-field, better market value due to its firmness during cooking, and its ability to provide consistent food for the family in the dry season. ‘Sisay’ is widely grown in Yilmana because of its preferred market traits, good late blight resistance, higher yield and good storability.

2.3.4 Potato production systems

Cropping seasons and the primary production constraints of the surveyed districts are indicated in Table 2-1. The majority of the farmers in these districts reported growing potato twice a year, except at Laigaint where 85 percent of the farmers grew potato only once per year (Table 2-5). Farmers in Shashemene have two dependable rainy seasons (Meher and Belg) and all of the farmers in this district reported growing potato twice a year while the farmers in Quarit and Banja reported three cropping seasons that are completely dependent on rainfall. Yilmana and Laigaint districts have two cropping seasons of which one is totally dependent on rainfall; the other is supplemented with irrigation.

Planting dates differed among varieties in Laigaint, Quarit and Yilmana during the Belmehr season. At Laigaint, the 'Abalo' variety is planted from February to April depending on when rain begins while 'Siquare' and new varieties are planted from April to May. Although rainfall in the dry season is erratic and not dependable for potato production in the Amhara region, farmers plant local varieties 1 to 3 months ahead of the main rain season anyway. The reason why Amhara farmers do not grow potato in the main rainy season needs investigation and analysis of different issues including biotic and abiotic factors. The farmers in Gumer & Geta plant new varieties during June to July but they do not grow local varieties then because of late blight pressure.

Pest and disease management practices differed among the districts (Table 2-5). Farmers from Shashemene, Gumer & Geta and Yilmana reported heavy late blight pressure in the main rainy season. However, only farmers from Shashemene (95%) and Gumer & Geta (88%) spray fungicide to control the disease. Some farmers (about 25%) in Yilmana spray Malathion on stored seed potatoes for control of tuber moth, a serious pest in this district.

Intercropping of potato with other crops such as maize, field pea, brassica, linseed and wheat is widely practiced in the districts of the Amhara region while this practice is not common in the Shashemene and Gumer & Geta districts (Table 2-5). This practice has multiple advantages: when farmers intend to store potato in the soil for several months planting a second crop before potatoes have matured gives the relay crop a head start. Planting a relay crop among potato plants as they are dying down gives the relay crop an earlier start. Also the maturing potatoes will offer little competition for the relay crop. It also diversifies the crop for risk management.

Most of the farmers in the study districts, except in Laigaint and Banja, apply chemical fertilizer to their potato crop (Table 2-5). At Laigaint, fertilizer application is a relatively new practice (about 58% of the farmers applied fertilizer for their potato crop). When growing new varieties Laigaint farmers consider fertilizer application a necessity. At Banja, where the soil is highly acidic, farmers don't use chemical fertilizers at all; instead most of the farmers use compost and animal manure as revealed from focus group discussions. Previously, Yazie et al. (2009) had reported that 82.5% of the farmers in the Awi zone, which includes the Banja district, apply manure and compost for their potato crop. Most of the farmers in Shashemene (72%) and Quarit (68%) and some farmers in Yilmana (25%) apply only di-ammonium phosphate (DAP); this is not what the Adet and Holetta Agricultural Research Centers recommend, which is application of both di-ammonium phosphate and Urea (Desta et al. 2008; Woldegiorgis et al. 2008). This needs further investigation.

Table 2-5: Potato production practices by district, expressed in percentage of respondents

Practice	District					
	Shashemene	**Quarit**	**Yilmana**	**Laigaint**	**Banja**	**Gumer & Geta**
Grew two crops a year	100	90	60	15	55	87
Grew new varieties	17.5	0	80	37.5	5	99.4
Apply DAP & Urea	100	100	100	58	0	100
Apply DAP	71.8	68.4	25	0	0	0
Spray fungicide against LB	95	0	0	0	0	88
Spray malathion against PTM	0	0	25	0	0	0
Intercrop potato with other crops	0	81	65	37.5	25	0
Sample size	40	21	20	40	40	160

2.3.5 Farmers' potato storage practices

Farmers in the surveyed districts employ a variety of storage practices for both seed and ware potato (Table 2-6). We observed that there is no distinction between seed and ware potato storage practices except for those farmers who have adopted diffused light storage (DLS) for seed tuber storage only. DLS is a system for seed potato storage designed by CIP that helps to delay tuber physiological aging and results in short, strong tuber sprouts (CIP 1985). In this study 48%, 5% and 2.5% of farmers in Gumer & Geta, Yilmana and Laigaint, respectively, utilize DLS to store seed potatoes of new varieties. Our survey also revealed that most of the farmers in the Amhara region and Gumer & Geta employ 'in-field storage' (delayed-harvesting), while no farmer does this in Shashemene. Potatoes are left unharvested for up to 5 months in Quarit, Laigaint, Banja and Gumer & Geta and up to 4 months in Yilmana. After harvest, heaping potatoes in a dark house (either in a bed-like structure or on the floor) is a commonly used storage practice in all of the study districts. Our survey revealed that most farmers in Quarit, Banja, Yilmana and Laigaint practice dark house seed tuber storage, but few farmers in Gumer & Geta and Shashemene do.

About 20% of the farmers in Laigaint use underground pits to store 'Abalo'. In the Shashemene district, about 83% of the farmers pile potatoes in a fashion that allows ventilation and then cover the pile with crop residues (in a 'ventilated Gotera' structure). Placing seed tubers outdoors but in the shade for two weeks is commonly used to break tuber dormancy for the Meher crop in Shashemene.

Table 2-6: Farmers' potato storage practices expressed as percentage of sampled farmers

storage practices*	District					
	Shashemene	**Quarit**	**Yilmana**	**Laigaint**	**Banja**	**Gumer & Geta**
In-field storage and then dark-house storage	0	100	95	77.5	100	19.1
Dark-house storage	17.5	0	0	0	0	12.7
In-field storage and then underground pit	0	0	0	20	0	0.6
Heaping in ventilated condition and covering with crop residues (Gotera, etc)	82.5	0	0	0	0	12.7
In-field storage and DLS (for seed only)	0	0	5	2.5	0	48.4
Sample size	40	21	20	40	40	160

*There is no distinction between seed and ware potato storage except that DLS storage is for seed only

2.3.6 Seed source and seed flow

Sources of seed tubers across the study districts are summarized in Fig 2-3. Based on percent farm counts, 90%, 88% and 69% of farmers, respectively, in Gumer & Geta, Banja, and Yilmana save their 'own seed' from the previous crop. Purchasing seed in the market is also common, practiced by 41% and 32% of the farms surveyed in Quarit and Laigaint (both represent cool highlands), respectively. Seed from local markets is not a good option for the Yilmana, Banja and Shashemene districts because it can be a source of bacterial wilt disease. About 20% of farms purchase seed from neighbor farmers in Shashemene. In Laigaint about 14% of farms reported using seed of new varieties that was given as a gift from government and nongovernmental agencies. Seed exchange among growers is common in Yilmana and Quarit, 15% and 6.3%, respectively, of farms reported this.

Seed produced in one cropping season may or may not be used as seed for other cropping seasons. The last Belmehr seed is used for both Belg and Belmehr potato production throughout the Amhara region but not for Mesino production in Banja because there is not sufficient time to break tuber dormancy. Seed for Mesino production comes from the last seed produced in the Belg season. Harvested seed from the end of the Mesino season is used for Belmehr season production but is not used again for Mesino. (Planting dates and seed sources for these cropping seasons are shown in Table 2-1). In Gumer & Geta, where new varieties have been adopted, Belg seed is used for the next Meher as well as Belg production seasons. In Shashemene, seed from the Meher crop is used for the next Belg production and vice versa but Meher seed is not used for the next Meher season.

There is also seed flow within and between districts. Exchange of seed tubers is common between seed farmers in high elevation areas and growers in medium or lower elevation areas because farmers realize that seed from the higher elevations provide a healthy crop. Farmers in the Bulchana Kebele of Shashemene are mainly dependent on seed from higher elevation areas. Higher elevation areas are a source of seed of ‘Siquare’, also known locally as ‘Key Dinch’, for the lower elevation areas in Laigaint. That is why ‘Siquare’ has a better price at planting time than ‘Abalo’ does in the district. The farmers of Quarit district depend on seed from the Sekela area (outside of the survey districts) for Mesino potato production.

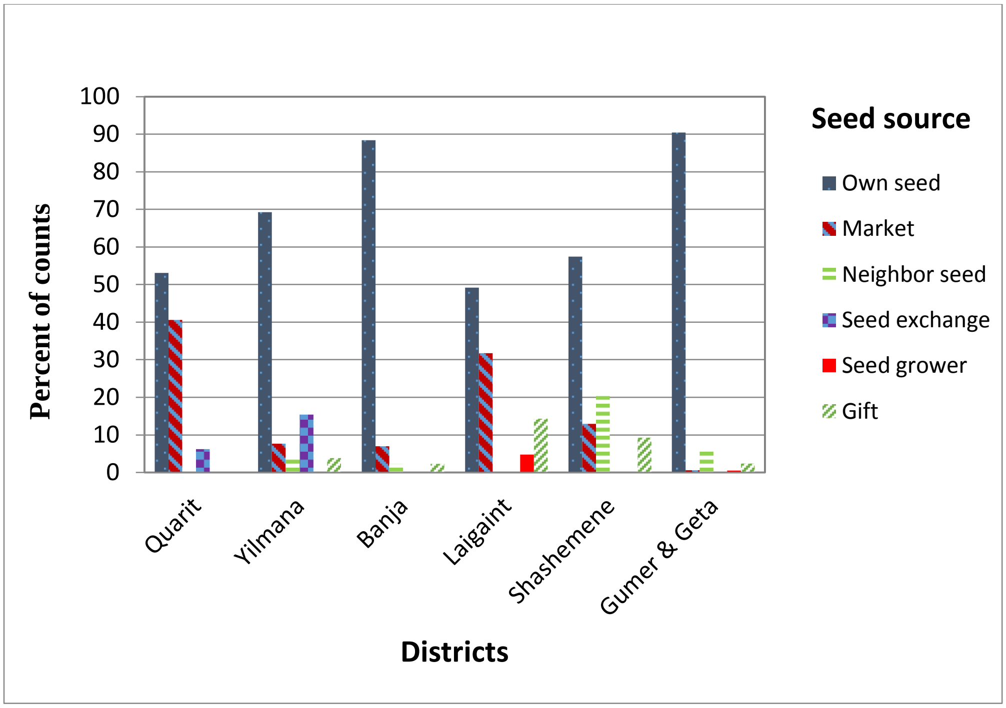

Figure 2-3: Potato seed tuber sources in different districts expressed in percent of farm counts

2.4 Discussion

2.4.1 Variety diversity at household level and distribution across different agro-ecologies and market access

Our study sought to assess potato variety diversity at both the household and district levels, in part to guide future conservation of current farmer-developed varieties, and in part to guide future breeding efforts. We found that 70-90% of the farmers in the districts surveyed grow two or more potato varieties at the same time in the same growing season. Some farmers grow up to five varieties, with widely different attributes, at a time. These results are consistent with a prior study by Garuma et al. (2013), who reported that farmers in Gumer & Geta grow more than one variety.

Brush et al. (1992) noted that individual households in Peru keep an average of 10 native potato varieties, and some keep up to 35.

Because small potato farmers are faced with many types of production risk, e.g., variation in timing and quantity of rainfall and occurrence of frost, growing more than one variety can reduce the risk of crop failure (Tsehaye et al. 2006; Abay et al. 2008) and allows farming in environments characterized by different soil, temperature and rainfall regimes (Lando and Mak 1994; Bellon 1996b). In addition to risk reduction, we found that Ethiopian potato farmers grow a diverse set of varieties to meet different needs, including food and market value, production timing constraints that can be met by utilizing cultivars that differ in maturity, and varieties that confer resistance or tolerance to biotic and abiotic stresses.

Of the 48 potato varieties recorded in our study, 40 were 'local' varieties and eight were 'new'. Twenty varieties are commonly grown by farmers; the rest are abandoned or rare. We also found that the distribution of these varieties is influenced by agro-ecology, market access and cropping season. 'Siquare', 'Abalo' and 'Samune' are the major local varieties in the Amhara region which fits well to the Belmehr cropping season but they are not common in Gumer & Geta and Shashemene areas. However, their degree of importance differed between agro-ecologies and market outlets even in the Amhara region. 'Abalo' is predominantly grown in sub-moist (dry) agro-ecology because it is drought tolerant while 'Siquare' is a dominant variety in moist agro-ecology. Yazie et al. (2009) and Labarta et al. (2012) also reported that 'Siquare' and 'Abalo' are the major potato varieties in the Amhara region but neither study mentioned 'Samune', which is mainly grown in sub-humid and acid soil areas in the region. 'Siquare' is also widely grown in other moist and cool Amhara region districts, including Sinan and Bibugn (Yazie et al. 2009) and in some parts of the SNNP and Oromia regions (Labarta et al. 2012). Labarta et al. (2012) estimated that ‘Siquare’ represented 25.5% and 35% of national and Amhara region potato production, respectively. Both Yazie et al. (2009) and Labarta et al. (2012) made a distinction between the varieties ‘Deme’ and ‘Ater Abeba’, considering them separate varieties. Nonetheless, DNA marker data (unpublished results) have revealed that ‘Deme’, ‘Ater Abeba’, ‘Key’, ‘Demas’ and ‘Siquare’ are actually a single variety.

Our survey data further indicates that ‘Agazer’ and ‘Nech Abeba’ are the major varieties in Shashemene, which represents a mid-altitude and bimodal rainfall pattern, while the new varieties ‘Gudene’ and ‘Jalene’ are widely grown in Gumer & Geta districts followed by the local variety ‘Hosana’. Emana and Nigussie (2011) and Abebe et al. (2013) also reported that ‘Agazer’ and ‘Nech Abeba’ are widely grown in the Shashemene district.

The influence of market access is another factor that determines which varieties are grown. ‘Agazer’ and ‘Nech Abeba’ are the major varieties that fit the requirements of the national markets, as they are suitable for stew, and have desirable skin color and tuber size. ‘Sisay’ is another variety that is mainly grown for the market. According to Emana and Nigussie (2011) Shashemene is a hub of national food and seed markets. For this reason, varieties widely grown in Shashemene areas are likely to be disseminated throughout the country.

In our study, the aggregate total area covered by new varieties (‘Gudene’, ‘Jalene’, ‘Sisay’, ‘Belete’, ‘Tolcha’, ‘Gera’, ‘Guasa’) was about 23% while the area allocated to these varieties at Gumer & Geta and Yilmana was 78% and 43%, respectively. Labarta et al. (2012) reported a similar value for adoption of new varieties at the national level (28.6%). The relatively small difference of our study to that of Labarta et al. (2012) is likely due, at least in part, to differences in districts that were surveyed for the two studies.

New varieties are grown mainly in the Meher cropping season because most of them have good resistance to late blight. In Gumer & Geta, new varieties are grown in both the Meher and Belg seasons. However, the majority of farmers in the Amhara region grow potato in the Belmehr (dry) season and plant local varieties, even though rainfall is not dependable for potato production. According to Bekele and Eshetu (2008), severe late blight infection in the Meher season forced farmers to limit their potato production to the dry season. Even if farmers realize significant production challenges and lower yields in the dry season, this crop helps meet the food deficit during the “hungry months” of July and August (Woldegiorgis 2013) when other crops have not yet been harvested. Farmers in Shashemene grow local varieties in both Belg and Meher seasons since they believe that existing major local varieties have moderate resistance to late blight (Table 2-3).

2.4.2 Farmers’ choice of potato varieties and selection concerns

Understanding how Ethiopian farmers decide what varieties to grow is important for guiding future variety development and dissemination efforts. We found considerable variation across the districts; it is obvious that many different varieties will be needed to address the multitude of needs. Late blight resistance, tuber yield and food value were important in all the districts. Drought tolerance, suitability for harvesting more than once in a season, tolerance to poor soil conditions, long dormancy, and market demand (for the Yilmana district) are the concerns in the Amhara region while market demand, early maturity and early dormancy traits are required in Shashemene.

A study by the International Potato Center (CIP 2008) revealed that yield, late blight resistance and early maturity are the attributes most frequently considered by farmers in Kenya and Uganda. In contrast, Abebe et al. (2013) reported these attributes are less important for farmers in

Shashemene. This difference might be attributed to the use of different benchmarks. The Abebe et al. (2013) survey included varieties that farmers consider to be resistant to late blight. Similarly, our study showed that a widely grown variety, 'Agazer', has good late blight resistance as indicated in Tables 2-3 and 2-4. However, this does not mean that late blight resistance is not a selection criterion for farmers. Instead, this shows that farmers select their own varieties suitable for their production area and practices. Our study also showed that Shashemene farmers grow early maturing varieties. New varieties such as 'Jalene' and 'Gudene' mature more than 20 days later than the widely grown local variety 'Nech Abeba' and as a result they mature too late to be used for the next season's planting. Thus, even though Shashmene farmers may not have been able to articulate when surveyed by Abebe et al. (2013) that early maturity is important for them, it clearly is.

The reasons for adoption of new varieties such as 'Gudene' and 'Sisay' in Gumer & Geta and Yilmana districts, respectively, may provide two important lessons for future potato breeding in Ethiopia to understand the needs and selection criteria of farmers as well as consumers.

Lesson 1: Farmers will accept a new variety if it meets several important needs, even if it also has some drawbacks. These new varieties are widely grown in these districts because they have several important traits that other new varieties do not. Even though 'Sisay' has bitter taste, it has good market acceptance because it stores well under local storage conditions, has good resistance to late blight and has traits that help it sell in the market (acceptable tuber size, color and shape, resistance to bruising during transportation, firmness during cooking). Similarly, for 'Gudene', although farmers complain that it does not digest easily when eaten during the first three months of storage and doesn't store well in home storage, it is high yielding, late blight resistant, has good storability in-field, good tolerance to tuber spoilage and good tolerance to several stresses.

Lesson 2: It is important to understand the needed characteristics of new varieties during variety development, and to appreciate the value of farmers' participation in the process of variety development. The research system does not currently provide important information about the characteristics of new varieties, even after release, because varieties are tested only for specific traits, primarily yield potential and late blight resistance. Farmers have complained about the suitability for boiling (in case of 'Sisay') and storability for food purposes (in case of 'Gudene'). These two traits are very important to farmers when they consider whether they will adopt a variety or not. Even so, through experience, farmers from both districts identified important traits of these two varieties and so continue to grow them. 'Sisay' was disseminated to Yilmana over 20 years ago. Promotion as well as dissemination of the variety was stopped because the research system realized that it is not suitable for boiling. However, the farmers do not want to lose this variety because they realized that it contains a unique set of traits that make it suitable for regional markets, along with other important traits such as good storability, late blight resistance and higher yield. Similarly, for 'Gudene', the farmers have come to understand that this variety has good storability in the soil and is resistant to tuber spoilage even during the main rainy season. Thus, they developed their own means to use this variety: they leave the potato unharvested and sow barley on it for the whole rainy season. After the barley crop is harvested, they harvest 'Gudene' for food and seed.

New varieties are grown in all the districts studied, with the exception of Quarit, where new varieties have not been introduced. 'Gudene' was disseminated to the Shashemene district but was not well accepted partly due to its longer maturity, which does not fit well with the existing cropping system, and partly because the choice of varieties in this district is not only determined by growers but also by marketers and consumers. Since ‘Sisay’ is not suitable for boiling, its acceptance in other districts is likely to be low.

2.4.3 Farmers’ decision making and variety diversity

Our study revealed that variety diversity at the household level is influenced by a range of production practices and environmental conditions such as pest and disease management, intercropping, soil fertility management, storage practices, seed sources and seed flows, and planting seasons. In mid altitude moist areas of the Amhara region, varieties with moderate resistance to late blight are common and the farmers in these areas do not grow late blight susceptible varieties such as ‘Abalo’ even in the Belmehr production season. ‘Siquare’, ‘Abateneh’ and several new varieties are alternatives for these areas. Suitability for intercropping is another factor that influences farmer decisions. Farmers in Quarit preferred ‘Siquare’ over ‘Abalo’ when they intercrop potato with other crops because of its short stature and early maturity. There are also varietal differences in relation to adaptation to low soil fertility. Chemical fertilizers are difficult to apply when growing potato in the dry season, in such situations farmers prefer ‘Abalo’ for its performance in soil with low fertility. ‘Siquare’ and new varieties are mainly grown around homesteads where soil fertility is good.

In our study we observed varietal differences in relation to cropping season and planting time. In the Amhara region, farmers have different varieties suited to late planting (if there is early onset drought) and early planting (if there is enough moisture during February and March). The farmers in Gumer & Geta plant new varieties (‘Gudene’ and ‘Jalene’) in both the Meher and Belg seasons but plant ‘Hosana’ and other local varieties only during the Belg season because of late blight pressure and heavy rainfall during the Meher season.

Seed sources and seed flows are important factors that influence the selection of varieties grown and help us to understand the diversity present in an area (Bellon 1996a). Our study showed that ‘own seed’ followed by seed purchased in the local markets are the major seed sources for farmers in all the study districts, consistent with what Gildematcher et al. (2009) and Samberg et al. (2013) have previously reported for Ethiopia. Our study also revealed that market, neighbor purchase and seed gift are important contributors for the adoption of new varieties. For instance, ‘Abateneh’ was introduced to Quarit from the Sekela area through the seed market system.

Farmers’ storage practices (for both food and seed purposes) also influences which varieties are grown. Current local varieties are well suited to available storage practices. However, some farmers in group discussion in the Amhara region complained that new varieties do not fit well with existing storage practices. For example, tubers of ‘Guasa’ and ‘Jalene’ rapidly spoil if they remain in the soil while others are liable to damage when stored in a dark house without ventilation. Therefore, when introducing a new variety, either the variety should fit well to existing storage practices or new storage technologies suitable for ware and seed potatoes should be developed and disseminated with the new varieties.

2.4.4 Factors determining farmers’ decisions to accept a variety

Many authors have identified the strong links between crop diversity and social, economic and cultural factors that together support diversity as a part of a dynamic system (Bellon 1996b). Consistent with this we found that variety diversity at the household level differed among districts due to the difference in agro ecological settings, farming systems, market outlets, extension activities, social aspects and others.

Potato variety adoption is also influenced by market preferences (CIP 2008). Our study found that the requirements of target markets have a significant impact on potato varietal diversity at the household level. Potato skin color is one of the main determining factors for variety preference in Shashemene, a hub of the national potato market. More than 98% of the farmers in this district grow white skin varieties, because that is what sells in the national market. For farmers who have access to markets, surplus produce can be sold immediately after harvest (as farmers in Shashemene do). For farmers like this, how well the variety performs in storage is not of great concern.

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CHAPTER 3: **GENETIC DIVERSITY AND RELATIONSHIPS AMONG ETHIOPIAN VARIETIES COMPARED TO MAJOR WORLD POTATO CLONES**

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Abstract

Potato is an increasingly important crop in Ethiopia, but the origin of 'local' varieties grown throughout the country is unknown. To evaluate the genetic diversity of Ethiopian potato varieties, and to assess their relationship with germplasm from North America, Europe and the International Potato Center (CIP), 8303 SNP markers were used to characterize 44 'local' Ethiopian cultivars, as well as 26 CIP, 22 American and 17 European potato clones. The marker data revealed that most of the local varieties were duplicates; among the 44 clones tested, only 15 unique genotypes were observed. Principal component and neighbor-joining dendrogram showed that American, European and CIP germplasm form three distinct clusters, with older Ethiopian varieties overlapping the European varieties, suggesting that the oldest local varieties are of European descent. Local varieties overall separated into two distinct clusters, suggesting that at least two distinct introductions gave rise to current local varieties in Ethiopia. Ethiopian germplasm harbors comparable levels of genetic diversity to American, European, and CIP germplasm and could provide the foundation for a national potato breeding program.

3.1 Introduction

Potato (Solanum tuberosum L.) is the world's third most important food crop in overall production after rice and wheat, and is a food security crop (Devaux et al. 2014) in some countries, including Ethiopia. The past few decades have seen a dramatic increase in potato production and demand in many developing countries (FAO 2014). In Ethiopia, potato production area has increased more than fivefold from 30,000 ha during the 1970s (Kidane-Mariam 1979) to more than 179,000 ha today (CSA 2014). The climate of the Ethiopian highlands is well-suited for potato production. That, combined with the need for a crop that can be harvested in August and September to meet seasonal food shortages, are two reasons why potato production has expanded so dramatically.

Although the International Potato Center (CIP) has worked with Ethiopian partners to introduce many new varieties over the past three decades, most Ethiopian farmers still grow older 'local' varieties (Labarta et al. 2011; Kolech et al. 2015). The origin of these varieties is not well understood, although it is clear that local varieties differ considerably from each other in terms of adaptation to the numerous ecological zones of the country, as well as for many important traits (e.g., storability, drought tolerance, marketability, suitability for making stew) (Abebe et al. 2013; Kolech et al. 2015). Seventy to ninety percent of Ethiopian farmers report growing at least two local varieties each year. Nationally, about 77% of Ethiopian potato land is planted to local varieties each year (Kolech et al. 2015).

Kidane-Mariam (1979) suggested that Ethiopian local varieties may have originated from a small number of introductions and reported that local varieties were low yielding. Because of the perception of poor yield, local varieties have received relatively little attention from the research community. Instead, variety improvement has centered on evaluating clones developed by outside sources, primarily CIP. Using this approach, the Ethiopian potato variety development program has released at least 29 potato varieties since 1987 (MOA 2013). In addition, three Dutch varieties have been registered in Ethiopia by a private company, SolaGrow. Nonetheless, only 23% of the production area is allocated to new varieties (Kolech et al. 2015), and only a few of the new varieties have been adopted (Woldegiorgis 2013).

Potato has been cultivated in Ethiopia since its introduction by a German botanist, Wilhelm Schimper, in about 1858 (Pankhurst 1964). The next known introduction was over 100 years later, in 1971-72, when several Dutch varieties were tested in the country (Kidane-Mariam 1979). There may have been introductions between 1858 and 1971, e.g., by missionaries, but we know of no documentation supporting this. After 1972, several authors reported the introduction of additional varieties (Yilma 1987; Lemaga et al. 1994; Woldegiorgis et al. 2001). In 1981, 27 commercial varieties were introduced from the Netherlands and tested under Ethiopian conditions (Lemaga et al. 1994). From these introductions only one variety, 'Krolisa', was released in Ethiopia, under the name 'Wechecha' (Kolech et al. 1998). According to Woldegiorgis et al. (2001), drought in 1985 resulted in the importation of more than 2340 tons of seed of European potato varieties. In any case, because Ethiopia lacks a variety registration system for local varieties, and does not have an advanced seed certification system, it is very difficult, if not impossible, to trace back the origins of current local varieties through historical records alone.

The first step in crop improvement in a developing country should be a full assessment of the local material (Williams et al. 1991). Similarly, Ortiz (2001) argued that including locally adapted potato germplasm in crossing would help ensure that the resulting varieties could be produced in a sustainable and environmentally-friendly manner. Maximum yield in potato might be achieved by maximizing heterozygosity and associated intra- and interlocus interactions (Mendoza and

Haynes 1974). Understanding how genetic variation is partitioned in a crop also has implications for crop conservation (Lung'aho et al. 2011).

Molecular markers are playing an increasingly important role in the management and utilization of plant genetic resources (Karp 2002). The recent development of a single nucleotide polymorphism (SNP) chip for potato has made it possible to assess genetic variation in a dosage-sensitive manner at thousands of loci simultaneously (Hirsch et al. 2013). Using the potato 8303 SNP chip, we evaluated genetic variation in local varieties collected from the two major potato production zones of Ethiopia (Northwest and South) as well as from varieties developed in America and Europe, and varieties developed by CIP. Our objectives were to: 1) assess the extent to which varieties in Ethiopia are known by different names (not uncommon in countries without a strong, formalized seed system); 2) examine the genetic diversity of Ethiopian potatoes; and 3) assess the relationship between Ethiopian cultivars, as well as to clones developed in other parts of the world (CIP, America and Europe).

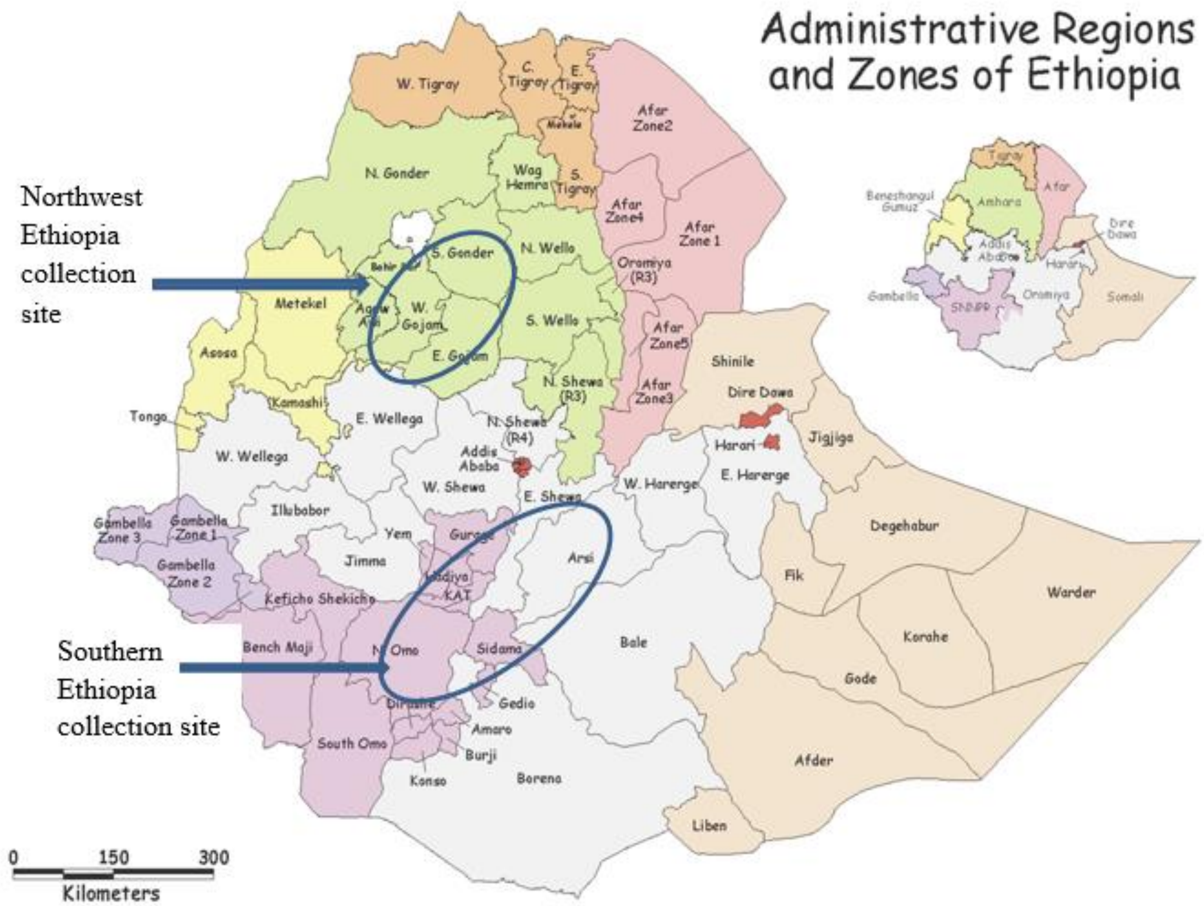
3.2 Material and Methods

3.2.1 Plant materials

Forty-four local varieties were collected from northwest (Amhara region) and southern (Oromia and SNNPR) Ethiopia during 2012 and 2013. The collection sites are shown in Fig 3-1. Ten to twenty-five tubers of each local variety were collected from either markets or farmers' fields, and their names recorded based on the knowledge of growers, traders and/or marketers. Details of the collections are shown in Table 3-1. Passport data including variety characteristics and estimated time of introduction were also collected at the time of collection but these data were not comprehensive. Each variety was planted in a screenhouse at the Adet Agricultural Research Center for morphological observation and genetic fingerprinting. At the same time, DNA was isolated from 31 CIP clones (17 'improved' varieties and 14 advanced clones) from research fields at the Adet and Holetta Agricultural Research Centers. The improved varieties represent those introduced into Ethiopia from CIP research sites in Peru and Kenya at different times, which were subsequently tested and ultimately officially released for production in Ethiopia. The CIP advanced clones represent new introductions for evaluation as possible new varieties. Details of the CIP materials are shown in Table 3-2. SNP data of 22 widely grown American varieties were generated previously (Hirsch et al. 2013). SNPs from European clones were collected using the same SNP chip as for the Ethiopian, American and CIP clones. The American and European clones evaluated are summarized in Tables 3-3 and 3-4, respectively, and represent several market classes (chipping, French fries and table), as well as older and newer varieties.

3.2.2 Morphological Assessment

The vines, flowers and tubers of local varieties were characterized using descriptors for cultivated potato (Huaman et al. 1977) to complement the results of DNA analysis. For leaf and stem characteristics, stem color, shape of stem cross section, abaxial and adaxial leaf pubescence, leaf dissection, leaf size, leaf color, growth habit and branching habit were recorded. Flower characteristics measured included flower color, degree of flowering, and tendency to premature flower abscission. Tuber characteristics recorded after harvest include tuber skin color, tuber flesh color, tuber skin texture, secondary tuber color, tuber shape, and storability.



The map created by Disaster prevention and preparedness Commission (DPPC) Information Center UN OCHA-Ethiopia

Figure 3-1: Where local potato varieties were collected

3.2.3 DNA extraction and SNP genotyping

DNA was extracted from two young leaves of each clone (from screenhouse plants for local clones, and from field-grown plants of CIP clones) using the CTAB method of Mace et al. (2003). The quality of each DNA sample was checked by agarose gel electrophoresis and a Nano Drop spectrophotometer (Thermo Fisher Scientific, USA). Later, the DNA was sent to Cornell University and clarified using a QIAGEN DNeasy Plant Minikit (QIAGEN, Germantown, MD). The DNA was then sent to Michigan State University and genotyped at 8303 SNP loci using the potato Illumina Infinium array developed by the SolCAP project (Hirsch et al. 2013). Loci with low-signal intensity or that displayed no polymorphism, or that did not cluster well into discrete dosage categories were filtered out. Of the 8303 markers genotyped, data from 3696 were retained for evaluation of potato clone diversity.

3.2.4 Genotypic data analysis

To study the genetic relationship of Ethiopian local varieties to each other, as well as to clones from North America, Europe and CIP, a neighbor joining analysis was performed. The SplitsTree4 program version 4.13.1 was used to construct an unweighted pair group method with arithmetic mean UPGMA-based tree (Huson and Bryant 2006). Archaeopteryx version 0.9901 beta was then used to generate the tree image (Han and Zmusek 2009). Principal component analysis was conducted using JMP software (JMP pro 10.0.02). The SNP data were first converted into numeric data (AAAA = -1, AAAB = -0.5, AABB = 0, ABBB = 0.5, BBBB = 1), then the principal component analysis was computed from the correlation matrix.

Genetic diversity within Ethiopian clones and between major world potato clones (American, European and CIP) was calculated using a custom R script based on the method described by Thrall and Young (2000). After minor allele frequencies for each locus were calculated for a subgroup or all clones combined, expected heterozygosity values (chromosome inheritance model) for each allele were calculated as

$$H = 2*p^3*q + 4*p^2*q^2 + 2*q^3*p$$

where p is the major allele frequency, q is minor allele frequency, p + q = 1, the AAAB and ABBB genotypes are given a heterozygosity weight of 0.5, and AABB genotype is given a heterozygosity weight of 0.667 (Bever and Felber 1992). Expected heterozygosities for each subgroup (HS), and for all clones combined (HT), were calculated by averaging expected heterozygosities across all loci. Genetic differentiation of each group relative to all potato clones (F_{ST}) was calculated as F_{ST}= (HT-HS)/HT). Expected heterozygosity of each of the 3696 loci for each of the four groups were arranged in four columns in Excel and exported to JMP software (JMP pro 10.0.02). Then, t statistics were computed to test whether expected heterozygosity between groups are significantly different. Similarly, genetic differentiation between groups were arranged in the same way as expected heterozygosity and t statistics were computed to test pairwise differentiation between groups using the same software.

In addition, population structure was evaluated using STRUCTURE software (Pritchard et al. 2000) using an admixture model. 15000 replicates were performed for each data set for k set to 3 (and separately, k set to 4) populations with a burn-in-time of 15000.

Table 3-1: List of Ethiopian potato clones sampled along with their collection sites

Code	Common name	Collection site	State
01	Nech Abeba	West Wondo	South
02	Durame Shule	West Wondo	‘
03	Key Abeba	Shasho	‘
04	Fayzer	Azo Tala	‘
05	Nech	Azo Tala	‘
06	Feleke	Chencha	‘
07	Akime	Genko	‘
08	Gedigala	Aderagot	‘
09	Asmera	Damote Gale	‘
10	Achire	Damote Gale	‘
11	Durame	Damote Gale	‘
12	Agazer	Shashemene	Oromia
13	Bulle	Kofele	‘
14	Key Shule	Shashemene	‘
15	Nech Abeba	Shashemene	‘
16	Key	Woyra	‘
17	Achire China	Kofele	‘
18	Holland	Limu Belebel	‘
19	Key	Bekoji	‘
20	Gojjame	Bekoji	‘
21	Abalo	Yilmana	Amhara
22	Samune	Yilmana	‘
23	Siquare	Yilmana	‘
24	Rejim Siquare	Yilmana	‘
25	Abadamu	Yilmana	‘
26	Abalo	Quarit	‘
27	Samune	Quarit	‘
28	Abateneh	Quarit	‘
29	Ayito	Quarit	‘
30	Abadamu	Quarit	‘
31	Abalo large	Quarit	‘
32	Siquare	Quarit	‘
33	Achire	Quarit	‘
34	Kuchibiye	Sinan	‘
35	Demie	Sinan	‘
36	Agere	Sinan	‘
37	Enat Beguaro	Sinan	‘
38	Abadamu	Sinan	‘
39	Tikure	Laigaint	‘
40	Key	Laigaint	‘

Code	Common name	Collection site	State
41	Komitate	Injibara	‘
42	Abalo	Injibara	‘
43	Mirit	Injibara	‘
44	Abathunegn	Sekela	‘

Table 3-2: List of CIP potato varieties, candidate varieties, and germplasm

Name	ID number	Remark
Menagesha	CIP-374080.5	New variety
Gera	KP-90134.2	‘
Challa	CIP-387412.2	‘
Sisay	CIP-378501.16	‘
*Awash	CIP-378501.3	‘
Gorebella	CIP-382173.12	‘
Zengena	CIP-380479.6	‘
Shenkolla	KP-90134.5	‘
Hundie	KP-90147.8	‘
Bulle	CIP-387224.25	‘
Belete	CIP-393371.58	‘
Gabisa	CIP-387096.11	‘
Araarsa	KP-90138.12	‘
*Guasa	CIP-384321.9	‘
Jalene	CIP-384321.19	‘
Gudene	CIP-386423.13	‘
Dagim	CIP-395096.2	’
CIP-396004.337		Candidate variety
CIP-396038.107		CIP advanced clone
CIP-396027.205		‘
CIP-396043.226		‘
CIP-395112.36		‘
CIP-391046.14		‘
CIP-396004.225		‘
CIP-393382.44		‘
*CIP-393385.39		‘
CIP-396036.201		‘
CIP-395111.19		‘
CIP-393280.57		‘
CIP-393280.82		‘
CIP-396034.103		‘

*These clones were not included in the final clustering and genetic diversity analysis

Table 3-3: List of American clones along with their pedigree and variety characteristics

Common name	**Pedigree**	**Variety characteristics**
Andover	Allegany * Atlantic	Early to medium maturity, chip and table stock
Atlantic	Wauseon * USDA B5141-6	Medium maturity, chip stock
Kennebec	B127 * USDA 96-56	Medium maturity, chip stock
Pike	Allegany * Atlantic	Medium maturity, chip stock
Snowden	B5141-6 * Wischip	Late maturing, released in 1990
Lamoka	NY120 * NY115	Late maturing, chipping stock
Lenape	USDA B3672-3 * USDA 47156	Medium late maturing, excellent chipping quality
Chieftain	LA 1354 * LA 1027-18	Medium maturing, table stock
NorDonna	ND206-1R * ND821-6R	Medium maturing, fresh market, released in 1995
Eramosa	F52047 * F60019	Early maturing, table stock, released in 1988
Superior	B96-56 * M59.44	Medium early maturing, fresh market, released in 1962
Garnet Chile	Introduced from Chile in 1845	Table stock
Irish Cobbler	-	Early maturity, old variety (reported in 1876)
Eva	Steuben * Bulk pollen from 107 clones	Medium maturing, table stock
Yukon Gold	W5279-4 * Norgleam	Medium early maturing, fresh market, french fry, released in 1981
Sebago	Chippewa * Katahdin	Late maturing, table and chipstock
Katahdin	USDA 40568 * USDA 24642	Main season maturity, primarily used for tablestock, released in 1932
Russet Burbank	A chimera selected from the variety Burbank in 1914	Late maturing, long term storage, excellent baking and processing
Russet Norkotah	ND9526-4 Russ * ND9687-5 Russ	Early to medium maturing, fresh market, released in 1987
Western Russet	A68113-4 * BelRus	Medium to late maturing, released in 2004
RioGrande Russet	Butte * A8469-5	Medium maturing, fresh market
Dark Red Norland	ND626 * Red Kote	Intermediate maturing, table potato

- No information about its pedigree.

Table 3-4: List of European potato clones along with their pedigree and specific characteristics

Common name	Pedigree and country of origin	Variety characteristics
Bintje	Munstersen * Fransen (Netherlands)	Medium early maturing, good for french fries, chips, boiling and baked, Bred in 1904
Spunta	Bea * USDA 96 56 (Netherlands)	Medium early, high drought resistant
Astrix	Cardina * SVP VE 70 9 (Netherlands)	Medium dormancy, good for french fries
Favorita	ZPC 50-35 * ZPC 55-37 (Netherlands)	Low dry matter content
Pentland Dell	Roslin Chania * Roslin Sasuma (UK)	High starch content, for table purpose, high drought resistant
Torridon	8372 a 17 * G5833 5 (UK)	Intermediate to late maturing, high dry matter content
Innovator	Shepody * RZ-84-2580	Early maturing, multipurpose, medium to high dry matter content
Hindenburg	Ismene * Jubel (Germany)	Late maturing, multipurpose use
Korona	-	-
Bzura	Pg232 * Prosna (Poland)	Very late maturing, moderate storage, high dry matter content, sterile
Kuba	Bzura * Karlena (Germany)	Early to medium maturing, good for french fries and chips
Greta	Magnum Bonum * Unica	Intermediate to late maturity, very high pollen fertility
Kerr's Pink	Fortyfold * Smiths Early (UK)	Very late maturing, good for chipping and frying, mashing and boiling, reported in 1907
Stirling	83186 * 8204 A 4 (UK)	Early maturing, fresh use
Sieglinde	Bohm 155/06 * Juli (Germany)	Early to intermediate maturity, poor for chipping, medium to high drought resistant
Kondor	Konst 61 333 * Wilja (Netherlands)	Early to intermediate maturity, poor for chipping and french fries, high to very high drought resistant
Picasso	Cara * Ausonia (Netherlands)	Intermediate to late maturing, not good for chipping

- No information about its pedigree and its characteristics.

3.3 Results

3.3.1 Identifying varieties by morphological and molecular characterization

Ten to twenty-five tuber samples of each local variety were collected from farmers' fields and markets. The names of each variety were provided by local farmers and traders. After collection, the tubers of each collection were planted in screenhouses to facilitate morphological characterization of each sample in detail. In the course of growing out the samples, we observed that seven of the 44 samples were variety mixtures, where the phenotypes of some plants in a sample were strikingly different from other plants in the same sample. Morphological descriptions collected from farmers or marketers during the course of collecting were used to identify which of the varieties in a mixture would be subjected to further analyses.

We also detected mislabeling in varieties handled by Ethiopian research centers. SNP analysis revealed that samples of the new varieties 'Awash' and 'Gabisa' were identical, as were samples of 'Tolcha' (UK-80.3) and 'Shenkolla'. We used CIP potato catalog and Ethiopian variety registry booklets to determine which varieties these actually are ('Gabisa' and 'Shenkolla', respectively).

Our genotyping and morphological evaluations further revealed that 'Sisay', a CIP-bred variety, is one of the most widely grown varieties in Yilmana (northwest Ethiopia). When we collected this clone, there was no reason to believe it was anything other than a local variety; because we could not get any written information about this variety in the Ethiopian potato variety registry. We later realized from the CIP catalog (Acquisition and Distribution Unit 2008) that this variety is one of the new varieties released in Ethiopia. Further, the defining morphological features of 'Sisay' in the catalog are identical to the morphological characteristics of our collection, 'Sisay'.

3.3.2 *Duplications within Ethiopian collections*

Farmers name potato cultivars based on varietal characteristics that they readily perceive. Most Ethiopian local cultivar names are based on descriptors such as texture, flower and tuber color, taste, or productivity. However, after conducting morphological and SNP comparisons, we found that some clones are known by many different names across the country. Of the 44 samples of local varieties, we found only 15 unique genotypes. The names and known synonyms of each of the 15 unique genotypes are shown in Table 3-5. For instance, a widely grown cultivar in northwest Ethiopia (West Amhara region) is known as 'Deme' or 'Demas' in Sinan, as 'Ater Abeba' and 'Siquare' in Yilmana, Quarit and some districts of the Awi zone, as 'Mirt' in Banja, and as 'Key Dinch' in Laigaint. The same variety is known as 'Key' in Bekoji and 'Woyra' in southern Ethiopia. A cultivar with the same morphology as 'Siquare', is known as 'Abateneh' at Sekela and 'Rejim Siquare' at Yilmana and Quarit. A surprising observation was that two improved varieties, 'Jalene' and 'Guasa', were found to be identical by both SNP and morphological analyses. These two varieties have long been considered siblings in Ethiopia, as it is known that both originated from the same CIP cross (Table 3-2). 'Jalene' was released by the Holeta Agricultural Research Center while 'Guasa' was released by the Adet Agricultural Research Center. It is remarkable that these two varieties were not known to be identical until now. Similarly, two CIP advanced clones, CIP-393382.44 and CIP-393385.39 are identical.

These duplications have misled previous authors, who reported the names of these varieties as if they represented different genotypes (Woldegiorgis et al. 2008; Tesfaye et al. 2008; Yazie et al. 2009; Labarta et al. 2011). For example, Tesfaye et al. (2008) reported 'Demie', 'Siquare' and 'Key Abeba' as if these names represented different varieties but our DNA and morphological analysis showed that they are identical. Adding to the confusion, the Hawassa Agricultural

Research Center released a new variety in 2005 known as ‘Bulle’ (MOA 2006) which, unfortunately, was already the name of a widely grown local variety.

In a few cases we observed distinct genotypes known by the same name. Traders at Hawassa refer to the distinct genotypes of ‘Durame’ and ‘Agazer’ as ‘Durame’, whereas all farmers in Shashemene (who supply the Hawassa markets) correctly identify these as different cultivars with different names. Similarly, consumers and traders in Bahir Dar city used the name ‘Key Dinch’ for both ‘Siquare’ and ‘Abateneh’.

It is important for future variety identification, research and breeding if each variety is known by one, and only one, unique name. Our proposed unique names for local varieties that are currently known by one or more duplicate names are shown in Table 3-5; in all cases, we propose the name that is most widely used at present. To differentiate the local ‘Bulle’ cultivar from the new ‘Bulle’ variety, which are genotypically and morphologically distinct, we propose renaming the local cultivar as ‘Bulle Local’.

Table 3-5: Proposed names for Ethiopian local varieties, along with known duplicate names, variety characteristics and areas of adaptation

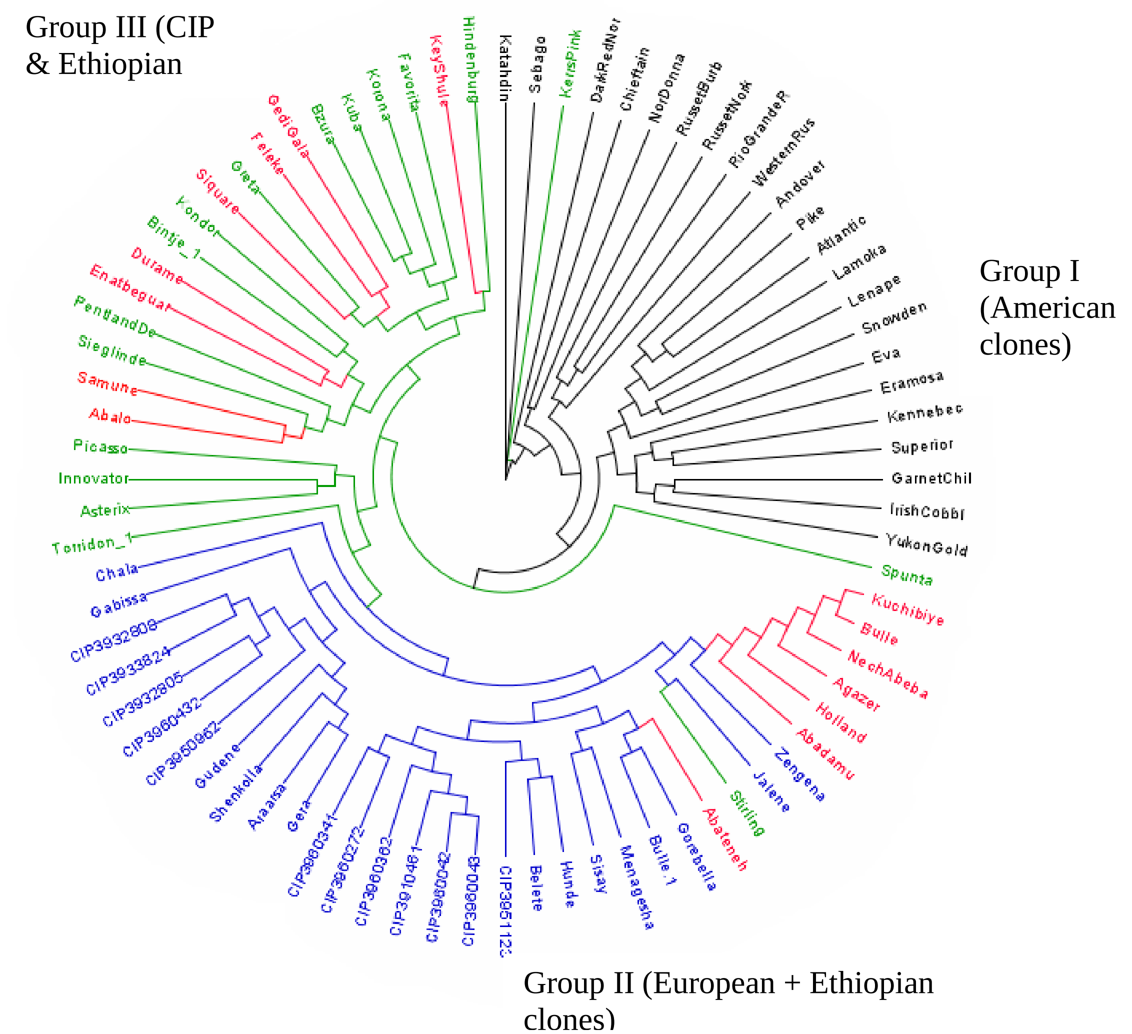
Proposed variety name (where grown)	**Known duplicate names (where grown)**	**Areas of Adaptation**	**Variety characteristics**
Abalo (Northwest Ethiopia)	Bayle Lakew (Sinan)	Cool highlands of Northwest Ethiopia	White flowers, many fruit, long dormancy, late maturing, oblong tubers
Abadamu (Yilmana)	Abalo Large (Quarit)	Cool highlands of Northwest Ethiopia	Large umbrella-shaped leaves, sets many fruit, long dormancy, shallow eyes
Enat Beguaro (Sinan)	Agere (Quarit and Yilmana), Amore (Quarit)	Sinan (Northwest Ethiopia)	Dense foliage, many stems per plant, does not flower, small oval-to-oblong tubers
Siquare (Yilmana)	Key Dinch (Laigaint), Mirit Zer (Banja), Demas (Quarit)), Deme (Sinan) Ater Abeba (Yilmana), Key (Bekoji and Woyira)	Northwest Ethiopia and some areas of South Ethiopia	Dense foliage, red flowers, many fruit, small leaves, early maturing, round tubers with red skin, medium-deep eyes
Samune	Samune (Quarit and Banja)	Banja district of Awi Zone	White flowers, flat and long tubers, long dormancy
Abateneh (Sinan and Quarit)	Siquare Long (Yilmana)	Sekela and Quarit districts in Northwest Ethiopia	Tall plants, red flowers, late maturing, round tubers with smooth red skin, deep eyes, medium storability in storage
Kuchibiye (Sinan)	Ayito (Quarit)	West and East Gojjam (northwest Ethiopia)	Tall plants, pigmented leaf vein, purple tubers, white flowers
Feleke (Chencha)	Akime (Genko)	South Ethiopia	Very late maturing, red flowers, round tubers with medium deep eyes
Durame (Damote Galle)	Asmera (Damote Dale)	Wolaita zone	Long dormancy, round to oval tubers
Agazer (Shashemene)	Durame Shule (Wondo)	East Arsi and South Ethiopia	Early maturing, small tubers, good shelf life, white flowers
Key Shull (Shashemene)	Key Abeba (Shasho), Achire China (Kofele)	East Arsi	Light pink flowers, oval tubers, large leaves, early maturing, short dormancy
Bulle Local	Bulle (Kofele), Fayzer (Azotella)	South Ethiopia	Tall plants, purple stems and leaf lamina, profuse white flowers, round purple tubers
Gedigala (Damote Galle)	Nech (Azo-Tella)	South Ethiopia	Large leaves, semi-erect, round to oval tubers, deep eyes, yellow tuber flesh
Nech Abeba (Shashemene)	Nech (Wondo)	Shashemene and surrounding areas	Profuse white flowers, round and white tubers, short dormancy
Holland	Holland (Limu Belbel)	South Ethiopia	Oval tubers, light pink flowers

3.3.3 *Genetic relationships among Ethiopian local cultivars and relationship to cultivars from CIP, America and Europe*

After removing duplicate genotypes, cluster analysis was performed again. Data from 3696 polymorphic SNPs was analyzed to construct the neighbor-joining dendrogram shown in Fig 3-2. With a few exceptions, potato clones from America (n=22), Europe (n=17) and CIP (n=26) separated into three distinct branches. Ethiopian clones (n=15) localized to the European and CIP branches; none clustered with American clones. The oldest varieties from northwest Ethiopia ('Enat Beguaro', 'Abalo' and 'Samune') and southern Ethiopia ('Durame') all grouped within the European branch. The southern Ethiopian local variety 'Key Shule', the widely grown local variety, 'Siquare', and the less widely grown local varieties 'Feleke' and 'Gedigala', group in a separate sub-cluster of the European branch.

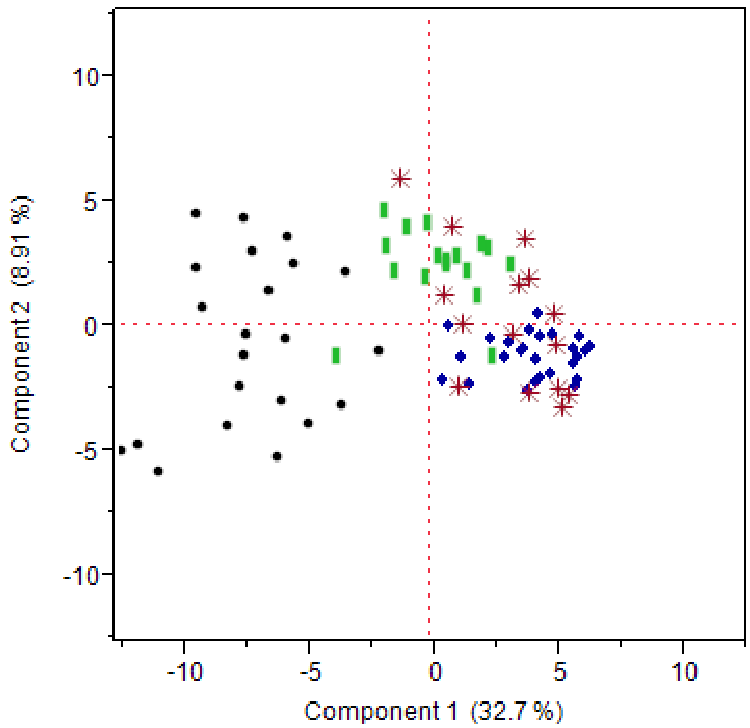
Two varieties from northwest Ethiopia ('Kuchibiye' and 'Abadamu') and major varieties from southern Ethiopia ('Holland', 'Nech Abeba', 'Agazer' and 'Bulle') group together with several of the CIP clones evaluated. 'Kuchibiye' and 'Bulle' are also similar morphologically, both being known by their pink tuber color and pigmented leaf veins. 'Abateneh' (from northwest Ethiopia) is the only Ethiopian variety that grouped in a distinct sub-cluster of CIP clones.

Genetic relationships were further assessed using principal components analysis, which showed that American, European and CIP-bred varieties group into three distinct clusters with relatively little overlap (Fig. 3-3). Most local varieties of northwest Ethiopia cluster with the European group while the dominant varieties of southern Ethiopia cluster with the CIP group.



American clones are shown in black, European clones are shown in green, CIP (International Potato Center) clones are shown in blue, and local Ethiopian clones are shown in red.

Figure 3-2: Clustering of varieties using neighbor-joining analysis of 3696 SNP markers.



The American clones are represented by black dots, the European clones are represented by green rectangles, the CIP clones are represented by blue diamonds, and the local Ethiopian clones are represented by red stars.

Figure 3-3: Principal components of the simple matching coefficient matrix, calculating from 80 potato varieties genotyped with 3696 polymorphic SNP markers.

3.3.4 Heterozygosity in Ethiopian potatoes compared to American, European and CIP clones

3696 polymorphic SNP markers were used to calculate heterozygosity (HS and HT). There are small but statistically significant differences in heterozygosity between Ethiopian, American, European and CIP cultivar groups (Table 3-6). Even though the Ethiopian cultivar group did not contain any unique SNP alleles (Fig 3-5), higher heterozygosity was observed in the Ethiopian group compared to the CIP group. The American group is the most heterozygous, and had more unique alleles than any other group, possibly because the SNPs on the chip were chosen for their polymorphism in American clones. The CIP group exhibited the lowest heterozygosity of all four groups.

Table 3-6: Mean SNP diversity for 3696 SNP markers

Group	Number of genotypes	Mean minor allele frequency	Expected heterozygosity[1]	Differentiation compared to all clones combined	Pairwise genetic differentiation (F_{ST})			
					American	European	CIP	Ethiopian
American	22	0.263	0.350 a	0	-	0.0707*	0.1314*	0.1097*
European	17	0.238	0.326 b	0.0191		-	0.0607*	0.0391*
CIP	27	0.223	0.306 d	0.0798			-	0.0217*
Ethiopia	15	0.228	0.313 c	0.0582				-
All clones	81	0.244	0.331	-				

[1]levels not connected by the same letters are significantly different at $P < 0.05$ at $t = 1.96$; *the values are significantly different at $P < 0.001$.

3.3.5 Genetic differentiation and population structure

Genetic differentiation was analyzed for each of the four variety groups compared to all potato clones combined, as well as between groups, as shown in Table 3-6. Pairwise genetic differentiation between groups showed that each group is statistically different from every other group, but the magnitude of each pairwise difference was small. The Ethiopian cultivar subgroup is more closely related to CIP and European clones than to American clones.

Population structure of the four variety groups was examined using STRUCTURE (Pritchard et al. 2000). The genetic structure of the four cultivar groups where three and four subpopulations (k) are assumed is shown in Fig 3-4. Genotypes were assigned to a sub-population if they had at least 50% membership within the group. The analysis for k=3 sub-populations indicated that American clones were in one group (blue sub-population), while most European genotypes were members of a second group (green sub-population) and all CIP genotypes were in a third group (red sub-population). Some Ethiopian genotypes localized to the CIP group and the rest localized to the European group, consistent with the cluster and principal component analyses. For k=4, only

American genotypes ended up being subdivided into multiple groups (Fig 3-4) consistent with the broader genetic diversity of this group. There was no additional subdivision for each group beyond k=4 (data not shown).

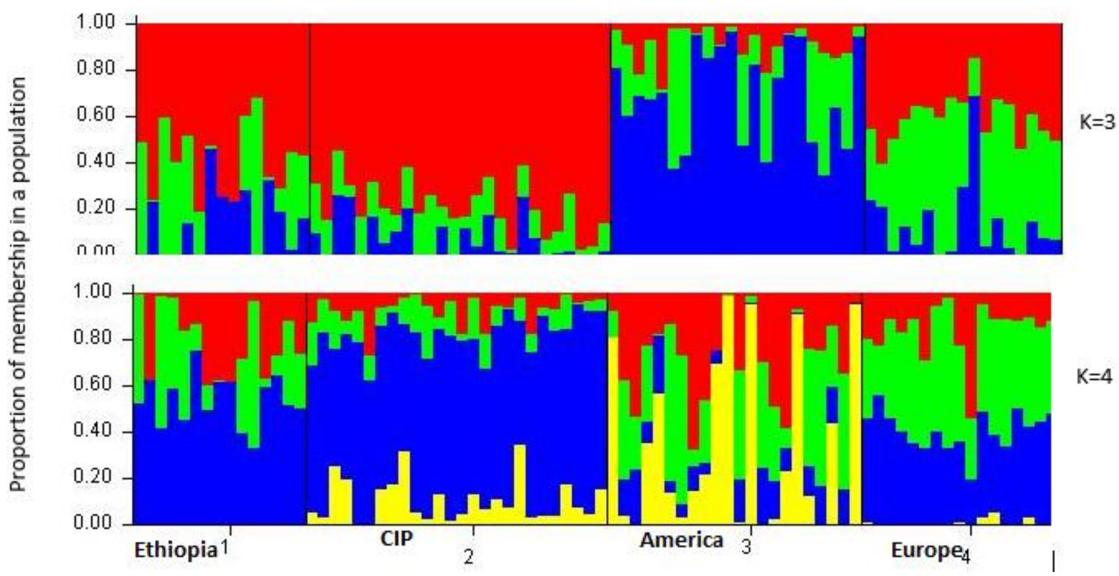


Figure 3-4: STRUCTURE analysis of 15 local Ethiopian potato varieties, 26 clones from CIP, 22 American clones and 17 clones from Europe (k=3 and k=4).

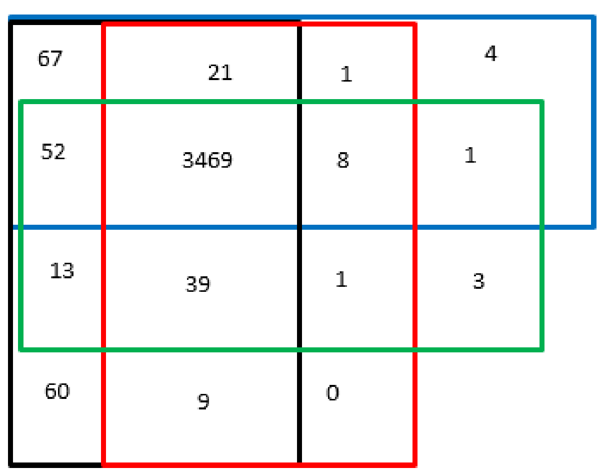


Figure 3-5: Number of unique and overlapping SNPs for each of four potato groups. Clones of each group were genotyped with 3696 polymorphic SNP markers. The North American, European, CIP and Ethiopian clones are represented by black, green, blue, and red rectangles, respectively.

3.4 Discussion

3.4.1 Causes of duplications among Ethiopian variety collections

Of the 44 local potato varieties evaluated in Ethiopia, we found only 15 distinct genotypes. Most of these 15 genotypes are known by different names in different parts of the country. The high frequency of duplications likely exists because the dominant seed system in Ethiopia is informal (Gildemacher et al. 2009; Hirpa et al. 2010): seed tubers are produced and disseminated without any regulations. The movement of seed tubers is common in Ethiopia (Samberg et al. 2013; Kolech et al. 2015). Agents for seed movement can be individuals, nongovernmental and governmental organizations, and farmers' cooperatives. During the Derg regime (1974-1987), farmers' cooperatives played a major role in moving planting material.

Farmers in different districts name potato varieties based on characteristics that they perceive. Most cultivar names are based on descriptors related to texture, color, taste, productivity and time to maturity. For instance, one widely grown cultivar in northwest Ethiopia ('Siquare' from Table 3-1) is currently known by many different names, where each name represents an attribute of this variety. 'Siquare' means sugary taste in Yilmana, Quarit and some districts of the Awi zone; 'Deme' or 'Demas' means dark-red tuber color in the Sinan district; 'Ater Abeba' means that the flower color is similar to the flower color of field peas; 'Mirt' means best in the Banja district; and 'Key Dinch' means red-colored potato in the Laigaint district. Similarly, 'Abateneh' means "father" in Sekela while in Yilmana this variety is known as 'Rejim Siquare' because it is taller than 'Siquare'. The name 'Ayito' means colored like a mouse because tubers are blue-black in color, while this variety is called 'Kuchbiye' in Sinana, which means late maturing.

The genotyping results reported here can serve as a first step in developing officially recognized names for local varieties. Our proposed names for each unique genotype, summarized in Table 3-5, can be taken as a starting point, since we know of no reliable historical records to determine the original name for each variety.

3.4.2 Origin and relationships among Ethiopian varieties

Although potato has been grown in Ethiopia for over 150 years, the origin of current local varieties is not known. Based on genetic relationships gleaned from molecular marker data (Fig. 3-2, Fig. 3-3), it appears likely that most local varieties in the northwest originated in Europe. Several authors have reported that many varieties have been introduced over the past 40 years from European countries as well as the International Potato Center (Peru) (Kidane-Mariam 1979; Yilma 1987; Lemaga et al. 1994). Some of these introductions may have become the 'local' varieties grown today. Alternatively, or in addition, it is possible that Ethiopian farmers selected 'local' varieties from naturally occurring crosses. The long growing season of the Belg and Belmehr seasons in the cool agroecological zones of Ethiopia favors the development of mature true potato seeds (TPS). Any seed that germinates can, in principle, become a new variety if it meets farmers' needs. Many Andean potato cultivars are believed to have been produced by farmer selection from naturally occurring variation (Bradshaw et al. 2006).

According to Ethiopian farmers, some local varieties have been grown for more than 40 years. These old varieties include 'Abalo', 'Samune', 'Enat Beguaro' and 'Durame'. All four of these varieties are most closely related to the European varieties tested. Some recent varieties, such as 'Siquare', are also most closely related to European cultivars. According to farmers, 'Siquare', the most commonly grown variety in northwest Ethiopia, has been grown for the last 25 years.

Morphologically, ‘Siquare’ looks like an Andigenea type, as it has small leaves and flowers profusely. Despite its similarity to European clones, it is not possible to confidently conclude that ‘Siquare’ originated from Europe, as CIP also uses European clones as parents.

Unlike northern varieties, the predominant southern varieties (‘Nech Abeba’, ‘Agazer’, ‘Bulle’ and ‘Holland’) are most closely related to germplasm developed by CIP. According to farmers, these varieties are not as old as most of the varieties in the Northwest. Thus, the major varieties of the South are likely of different origin than those in the Northwest. One or more of these varieties may represent direct adoption of clones introduced by CIP. Variety introduction from CIP began 32 years ago (Lemaga et al. 1994). According to Kidane-Mariam (1979), the first CIP varieties were tested in 1976 in central, southern and eastern Ethiopia (Holetta, Nazreth, Alemaya, Endiber, Chencha, Areka and Kulumsa).

Within Ethiopia it is believed that potato varieties introduced into the country during the past 23 years can all be traced back, since a National Seed Industry Policy was issued by the government in 1992 to regulate seed import and export (Bishaw et al. 2008). Even so, there are some cases, like ‘Abateneh’, a local Ethiopian variety that has been grown for the last 10 years, where it is impossible to find information about its origin. Molecular genetic characterization shows that ‘Abateneh’ is related to ‘Gorebella’ and ‘Bulle’ (new varieties that originated at CIP). It may be that tubers were taken from research fields during variety testing; CIP clones are tested in research plots in many parts of Ethiopia. It is also possible, but less likely, that ‘Abateneh’ was selected from TPS by farmers, where one or both parents were CIP clones.

3.4.3 Divergence, population differentiation and structure

It has been suggested that maximum heterozygosity leads to maximum heterosis and thus high yield in potato (Mendoza and Haynes 1974). Increasing the heterozygosity of Ethiopian local varieties and widening their genetic base are both likely to be important breeding activities as new Ethiopian cultivars are developed that possess desired combinations of abiotic and biotic stress tolerances and high yield. An unexpected result of this study is that Ethiopian clones are more heterozygous than the CIP clones tested. Our naïve expectation was that since CIP clones have genes from many different species, they would contain many unique alleles, and be more heterozygous. The reduced heterozygosity compared to Ethiopian clones, as well as lower numbers of unique alleles, compared to the USA, may be due entirely, or in part, to ascertainment bias, as the SNPs evaluated were pre-selected for being informative in US germplasm. As Hamilton et al. (2011) noted, novel alleles in CIP sources derived from wild species may not have been detected because SNPs for the infinium array were derived exclusively from cultivated potato.

American clones are not only more heterozygous but also have more unique alleles than the other three groups tested. Increased diversity in American clones may have resulted from the introgressions of several wild species that are common in the pedigree of many modern potato processing varieties.

It is abundantly clear from the heterozygosity analyses, and evaluation of private and shared SNPs, that Ethiopian varieties harbor considerable genetic diversity; this in turn negates the belief that Ethiopian potato varieties are derived from a markedly narrower genetic base than American, European or CIP clones.

3.4.4 *Implications for future potato breeding and conservation*

Breeders require sufficient genetic variation when developing new varieties adapted to changing environmental conditions and emerging pests and diseases. Such varieties are especially important for Ethiopian farmers, where low-input agriculture is the norm, and weather variability has increased in recent years. This study is the first to characterize Ethiopian potato genetic resources in relation to varieties from the International Potato Center, America and Europe, using molecular and morphological methods. We have found that current Ethiopian cultivars harbor considerable genetic variation, comparable to that found in CIP, European and American germplasm. American germplasm differs the most from Ethiopian material, suggesting that crossing with American varieties could help broaden the genetic base in Ethiopia. Moreover, the proposed name for each unique genotype is undoubtedly the first step in registering these varieties for future development of the crop and for conservation of these genotypes.

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CHAPTER 4: **GENOTYPIC VARIATION IN POTATO GROWTH AND YIELD RESPONSE TO WATER STRESS DURING COOL AND WARM SEASON PRODUCTION IN NORTHWEST ETHIOPIA**

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Abstract

Potato has become an increasingly important food crop in Ethiopia, especially in the northwest highlands when it is commonly grown in low-rainfall periods referred to as Mesino (relatively cool) and Belg (relatively warm) seasons. However, water stress during these periods constrains the crop from meeting full yield potential. Farmers tend to grow local varieties that they perceive to be more drought tolerant, but these varieties have not been evaluated under controlled conditions for their water stress tolerance. A replicated screenhouse experiment was conducted in northwest Ethiopia in 2014 to evaluate nine local varieties and several new varieties introduced in the region that some have reported to possess drought tolerance. All varieties were grown under two water regimes (well-irrigated control and stressed) maintained by monitoring soil moisture. Plant growth and morphological measures were included in the study to identify traits associated with water stress tolerance. Marketable and total tuber yields of the varieties were higher in the relatively cool (Mesino) compared to the warm (Belg) season, and averaging across varieties, the marketable tuber yield losses due to water stress in Mesino and Belg seasons were 28% and 67%, respectively. We observed substantial differences between varieties in growth and yield response to both growing season and water stress. In the Mesino season, no variety out-yielded the main local

variety, ‘Siquare’, under drought conditions, while the new introductions ‘CIP 395109.34’ and ‘Gera’ were among the highest yielding varieties in the Mesino season under both irrigated and stress conditions. In the Belg season, ‘Granola’ and ‘Abadamu’ had the highest marketable tuber yields under both irrigated and stress conditions. Traits associated with high marketable yield potential and stability under both irrigated and stress conditions included: high harvest index (HI); increased root length under stress; relatively low leaf area ratio (LAR); relatively few deformed and small tubers under stress. Our results indicate potential for improving dry season potato production in Ethiopia by utilizing both selected local and new varieties, and evaluating for identified traits associated with yield potential and drought tolerance. A next phase of the study will be expansion of stress evaluation under field conditions.

4.1 Introduction

Ethiopian agriculture is primarily rain-fed, and seasons of potato production vary regionally based on rainfall probability as well as temperature. While some potato production takes place during the “Meher” cool, rainy season (May or June to October), particularly in Shashemene and surrounding areas along the Rift Valley south of Addis Ababa, most of the nation’s potato production (more than 62% of 179,000 ha) takes place during relatively dry periods (CSA 2014), such as the short-rain “Belg” warm season (February to May), “Belmehr” season (March/April to August) or the relatively cool “Mesino” season (September to December). In the Mesino season plants often begin with good soil moisture during early plant establishment, but with declining rainfall become water stressed in the latter half of the growing season. Although yield potential is often constrained due to water stress in both the Belg and Mesino seasons (Kolech et al. 2015), and growers risk severe yield losses due to severe drought in some years, this period is nevertheless often chosen for potato production because the risk of crop failure due to late blight is reduced in dry seasons (Bekele and Eshetu 2008). Also, dry season potato production can fill a critical food gap during the "hungry months" (Woldegiorgis et al. 2008; Woldergiorgis 2013; Kolech et al. 2015).

While potato is generally considered a drought-sensitive crop (Lalou et al. 2003; Wishart et al. 2013), Alexandratos (1995) reported that some production can be achieved with suboptimal rainfall where other crops fail. Potato is the only food crop grown to any large extent in the dry season under rain-fed conditions in Ethiopia (Kolech et al. 2015). Although yields can be low with water deficits, some potato varieties maintain a relatively high harvest index (HI) under both irrigated and drought conditions (Wolfe et al. 1983) and can produce more food per unit of water than many other major crops (FAO 2009). Also, some varieties used in Ethiopia have early maturity (i.e., short growing season), which can avoid or minimize exposure to water stress periods. Stress avoidance can be as important as stress tolerance for consideration in evaluating potato varieties for low rainfall conditions (Levy et al. 2013). The magnitude of drought impact on potato production vary depending on the duration and severity of the stress in relation to the plant's phenological stage (Jeffery 1995). Plant emergence and tuberization are phenological stages when potato is most sensitive to water stress, so availability of water at these stages can minimize negative effects on tuber yield (Martinez and Moreno 1992).

Drought tolerance is a complex trait and considerable genotypic variation in tolerance has been documented for potato. Cabello et al. (2012) evaluated 918 accessions from the CIP world potato collection under field conditions with full and deficit irrigation. They found a range of response from 52% reduction in tuber yield under water shortage within the subset of genetic stocks, to only 38% reduction in the subset of Andean landraces. Hassanpanah (2010) evaluated 7 potato varieties and identified two (‘Kennebec’ and ‘Caesar’) as relatively drought-tolerant based primarily on tuber yield and water use efficiency at low water supply. Wolfe et al. (1983) also found ‘Kennebec’ relatively drought-tolerant in terms of marketable yield compared to ‘White Rose’, and this was due primarily to fewer small and misshapen tubers under drought conditions for ‘Kennebec’. Lahlou and Ledent (2005) identified two potato varieties, ‘Desiree’ and ‘Monalisa’, as tolerant to water stress, and Schafleitner et al. (2007) identified ‘Col.155’ as a stable clone in both drought and control conditions. The extensive evaluation by Cabello et al. (2012) found that accessions with high yield under irrigated conditions also tended to yield well under drought conditions, so yield potential and stability are important evaluation criteria.

Drought tolerance in potato has been attributed to various growth and physiological traits (Monneveux et al. 2013). In addition to maintaining high harvest index and tuber quality under drought stress, root traits such as rooting depth are an important selection criteria for improving yield in drought conditions (Lynch 2007; Lahlou and Ledent 2005), as well as above ground growth (Vos and Haverkort 2007).

Most of the farmers who grow potato in Ethiopia in the dry season grow local potato varieties. The use of improved varieties from outside sources (e.g., CIP, the International Potato Center) is not common in low rainfall seasons. Ethiopian potato growers reported preference for selected local varieties under drought conditions (Kolech et al. 2015), with the assumption that these varieties are either early maturing or have a deep root system. In every agro-ecological zone in Ethiopia farmers have varieties they prefer for their growing locations and seasons. However, the varieties have not been evaluated under controlled and replicated experiments to evaluate performance under drought conditions. Therefore, the present study was conducted to evaluate major Ethiopian local varieties for their drought tolerance under controlled conditions in two growing seasons, and to compare these with a few selected varieties from outside sources. The study was designed to evaluate several potential screening parameters as indicators of drought tolerance.

4.2 Material and Methods

4.1.1 Experimental site and planting seasons

The experiment was conducted in a screenhouse at the Adet Agricultural Research Center, near Bahir Dar, Ethiopia (elevation 2200 m.), and was repeated in two growing seasons, the Belg (from Feb 21 to June 18) and Mesino (from October 3 to January 23). The Belg short-rain season is relatively warm and the use of supplemental irrigation is common. The Mesino is a relatively cool growing season where farmers in northwest Ethiopia rely on the residual moisture of the prior rain season (Meher) to establish the plants, and dry conditions prevail in the latter half of the growing season with no supplemental irrigation. Rainfall distribution in both the Belg and the Mesino production seasons is erratic and seldom optimum for potato production. The historical average minimum and maximum temperatures and rainfall of the site in both growing seasons are shown in Fig 4-1.

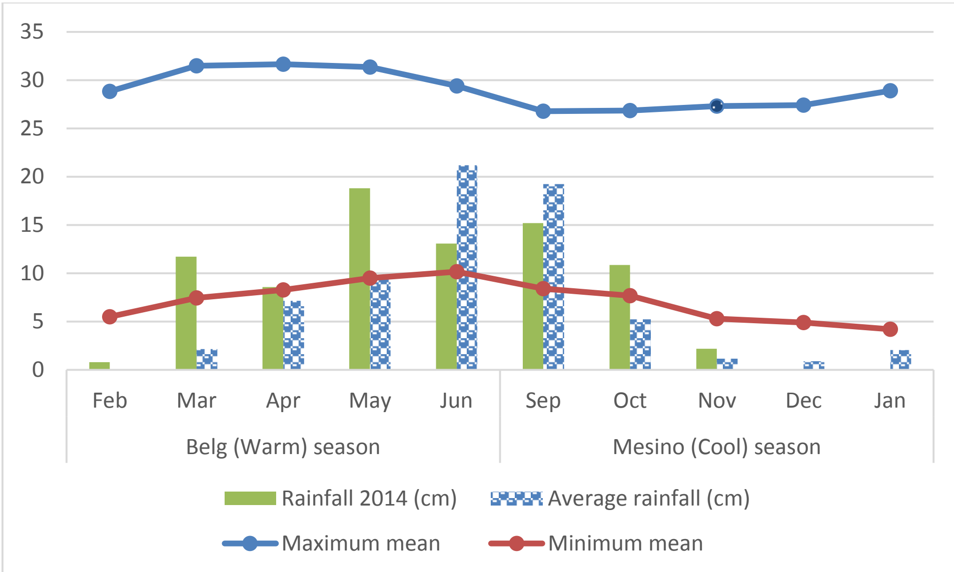

Figure 4-1: Historical mean monthly maximum and minimum temperature (°C) and rainfall (cm) of the Belg (warm) and Mesino (cool) seasons at the Adet Agriculture Research Center.

4.1.2 Varieties evaluated

Nine local potato varieties were selected for evaluation, based on a variety diversity management survey conducted in Ethiopia during 2012 (Kolech et al. 2015). To avoid confounding effects from seed-borne diseases, these varieties were tested for six common viruses and bacterial wilt. Samples that tested negative for these diseases were multiplied in-vitro and in a screenhouse for inclusion in the experiment. To confirm that these varieties are genetically divergent, they were genotyped with 8303 SNPs, using the potato Illumina Infinium array developed by the SolCAP project (Hirsch et al. 2013). One German variety, 'Granola' and one CIP advanced clone (CIP-395109.34) were included because of reports that they have better tolerance to water stress. In addition, recently released varieties (from CIP) that are currently being grown in some regions of Ethiopia were also included. Key characteristics of all varieties evaluated are shown in Table 4-1.

Table 4-1: Key characteristics of varieties evaluated, organized by origin and maturity class

Varieties	Origin	Maturity	Storability	Adaptation areas
Key Shull	Local collection	Very early maturing	poor	Shasho District, SNNP region
Siquare	"	Early maturing	good	NW Ethiopia
Agazer	"	Early maturing	good	SNNP and Oromia regions
Nech Abeba	"	Medium early	poor	SNNP and Oromia regions
Abadamu	"	Medium early	excellent	Quarit District, NW Ethiopia
Bulle	"	Medium late	poor	Kofele district, Oromia region
Enat Beguaro	"	Medium late	poor	Sinan District, NW Ethiopia
Rejim China	"	Late maturing	poor	Kofele District , Oromia region
Abateneh	"	Late maturing	medium	Quarit and Sekela, NW Ethiopia
Granola	European variety	Early maturing	good	http://www.solana.de/news_details/items/granola-is-potato-of-the-year-2014.html
CIP-395109.34	Advanced clone	-	-	-
Sisay	CIP- Improved variety	Early maturing,	good	Yilmana, NW Ethiopia
Gera	"	Early maturing	good	Reported to be well adapted to dry areas above 2700 m.asl
Belete	"	Early maturing,	medium	Reportedly widely adapted variety
Jalene	"	Medium early maturing	poor	Reported widely adapted variety in Ethiopia

- Not reported; NW= Northwest Ethiopia; SNNP= Southern Nations, Nationalities and Peoples State

4.1.3 Experimental design and water stress treatments

Disease-tested seed tubers of the varieties were planted into well-drained square plastic pots (30 cm wide and 37 cm deep) filled with soil composed of 25% sand, 25% animal manure, and 50% clay loam. Three grams of diammonium phosphate (DAP) were applied to each pot prior to planting. In each growing season trial the treatments were laid out in the screenhouse in a randomized complete block design. In the Mesino season evaluation there were 15 varieties x 2 irrigation treatments (optimal and stressed) x 4 replications x 2 pots per replication = 240 pots. Three of the varieties (‘Abateneh’, ‘Agazer’ and ‘Belete’) were not included in the Belg season evaluation. Watermark soil moisture sensors (Irrometer Co. Riverside, CA USA) were placed at a 20 cm depth in a minimum of 8 pots of each irrigation treatment, with pots selected to represent the range of plant size and maturity classes among the varieties. The water stress was imposed such that it reflected typical rainfall and water stress patterns under field conditions in the Mesino growing region and early season irrigation typically used in the Belg season. All pots were well irrigated (water applied when average soil water potential among the monitored pots reached -0.03 Mpa) until 45 days after planting, after which the stressed treatment was not irrigated again until soil water potential was lower than -0.08 Mpa (similar to the water stress level imposed by Lahlou and Ledent 2005). About 15 days after most varieties had reached 75% flowering, all pots were again maintained well-irrigated for the final growth stage.

4.1.4 Plant growth, biomass partitioning, and yield measurements

One pot of each variety from each replication of both treatments was selected for destructive harvest at the stage when all varieties had reached maximum plant height, above-ground biomass and green leaf area, and some of the early-maturing varieties were at or near full maturity. A second destructive harvest occurred about 15 days later (Belg season) or 20 days later (Mesino season), when late as well as early-maturing varieties were at full maturity, and all varieties had presumably reached maximum tuber yield.

Data collected at the first harvest included: plant height, specific leaf weight (SLW, leaf dry mass per unit leaf area), estimated total plant leaf area, and maximum root length. Green leaf color index data were collected with a SPAD meter (SPAD-502, Minolta, Japan), which is highly correlated with leaf chlorophyll per unit leaf area (Barraclough and Kyte 2001). Leaf area was determined with a LI-COR leaf area meter (LI-3000, Lincoln, NE USA) for three leaves collected from the upper, middle and lower portions of the plant canopy. These leaves were then oven-dried at 70ºC until constant weight was reached. Total leaf area per plant was then estimated using the ratio of leaf area to leaf dry weight and multiplied by the total green leaf dry weight as described by Wolfe et al. (1983).

At the second and final destructive harvest, plant parts were carefully washed and separated into leaf, stem, root + stolon, and tubers. Total tuber number was recorded and tubers were separated into marketable, unmarketable (small, <30 g), deformed and green. All plant parts were separately oven-dried at 70ºC to constant weight. Harvest index (HI) was calculated as the ratio of total tuber dry wt/ total biomass (tuber + root + stolon + leaf + stem dry wt). Leaf area ratio (LAR) was calculated as the ratio of total leaf area/total plant dry wt. Stress susceptibility index (SSI) was computed for both marketable and total yields as described by Hassanpanah (2010):

$$SSI = (1 - Ysi/Ypi)/(1 - Ys/Yp),$$

Where Ysi and Ypi are the dry weight yield of variety "i" under stress and normal conditions, respectively, and Ys and Yp are the average dry weight yield of all varieties in the trial under stress and normal conditions, respectively. SSI values < 1.0 indicate that variety "i" is less stress susceptible than the average of other varieties in the trial.

4.1.5 Data analysis

Analysis of variance (ANOVA) for main effects (variety, water treatment, season) and their two-way and three-way interactions for plant height, root length, SPAD reading, leaf area, tuber number, total tuber yield, marketable tuber yield, and HI was performed using JMP PRO 10.0.2 software (SAS Institute 2012). A correlation matrix between measured growth and morphological parameters and tuber yield was developed from data from both treatments and growing seasons. An Additive Main Effects and Multiplicative Interaction (AMMI) model was used to partition variety by environment (season and water regimes) interaction and construct biplots. AMMI analysis was computed using Genstat software (Genstat 2013).

4.3 Results and Discussion

4.1.6 Seasonal effect on drought tolerance ability of potato varieties

The experiment was conducted targeting two relatively dry potato production periods in Ethiopia: the Mesino (cool) and Belg (warm) growing seasons. Planting potato for the Mesino season occurs at the end of the main rainy season (end of August to first week of September), so soil moisture in the first 30-45 days is typically sufficient for early plant establishment, but water availability declines and water stress is common at later growth stages (Fig 4-1). The Belg season typically begins at low soil moisture followed by increasing, but erratic and undependable rainfall so that supplemental irrigation is a necessity. Since irrigation water is a scarce and shared resource, farmers who irrigate at planting in the Belg season may not have access to irrigation water again for several weeks.

Table 4-2 provides a comprehensive summary of ANOVA for the plant growth (Table 4-3) and tuber yield and HI data (Table 4-4). Potato tuberization is favored at relatively cool temperatures (Menzel 1980), and averaging across irrigation treatment and variety, we found that plants grown in the cool Mesino season were in general more productive, with higher HI than in the relatively warm Belg season. Season main effect on plant height, root length, total and marketable tuber yield, and HI were statistically significant at $P < 0.0001$ (Table 4-2). The Belg season also had more unmarketable small, deformed and green tubers than the Mesino season (Table 4-5). Higher SPAD readings (or green color index) and total tuber number per plant were observed in the Belg season than that of Mesino.

Averaging across varieties, the marketable yield reductions due to water stress were 28% and 67% in the Mesino and Belg seasons, respectively (Table 4-4). There was also a greater decline in plant height (Table 4-3) and HI (Table 4-4) with stress in the Belg compared to the Mesino seasons, and the Season x Treatment interaction effect for these parameters was statistically significant (Table 4-2). This shows that the impact of drought in the Belg season is more severe than that of Mesino.

Averaging across irrigation treatment, growing season had a substantial effect on the relative ranking of varietal performance, with a statistically significant Season x Variety interaction effect on most parameters measured (Table 4-2). For example, ‘Jalene’, ‘Rejim China’, ‘Siquare’, and ‘Sisay’ all had better than average marketable tuber yields in the Mesino season, but all of these performed relatively poorly in the Belg season (Table 4-4).

Table 4-2: Analysis of variance results for selected data collected

Parameter	Plant height	Root length	SPAD reading	Leaf area	MTY	TTY	TTN	Harvest index
Season	<.0001	<.0001	<0.0001	NS	<.0001	<.0001	<.0001	<.0001
Treatment	<.0001	0.0004	<0.0001	<.0001	<.0001	<.0001	NS	<.0001
Variety	<.0001	<.0001	<0.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Treatment* Variety	NS	NS	NS	0.0328	NS	NS	NS	NS
Season*Treatment	0.001	NS	0.0263	NS	NS	NS	NS	<.0001
Season*Variety	<.0001	0.0201	<0.0001	0.0043	0.0038	<.0001	<.0001	<.0001
Season*Treatment* Variety	NS	NS	NS	NS	NS	NS	NS	NS

MTY= Marketable tuber yield per plant (g/plant); TTY= Total tuber yield per plant (g/plant); TTN= Total tuber number per plant

4.1.7 Genotypic variation in drought response

Plant height, leaf area, and marketable and total tuber yield declined in stressed compared to well-irrigated treatments in almost all cases (Tables 4-3, 4-4), reflecting the sensitivity of the potato crop to drought (Wishart et al. 2013; Lalou et al. 2003). However, yield potential and the magnitude of decline with stress varied among genotypes. The ‘CIP 395109.34’ and ‘Gera’ entries were among the highest yielding varieties in the Mesino season under both irrigated and stress conditions. However, these varieties did not outperform the widely grown variety, ‘Siquare’ under stress conditions. In the Belg season, ‘Abadamu’ and ‘Granola’ had the highest marketable tuber yields under both irrigated and stress conditions. ‘Granola’ gave 92.6% and 94.7% marketable tuber yield advantage over ‘Siquare’ in irrigated and stress conditions, respectively, in the Belg season. All four of these showed relatively high yield potential and stability across stress treatment and growing season compared to the other varieties in the trial.

Stress susceptibility index does not take into account yield potential, but focuses on percent decline in performance due to stress relative to other varieties in a trial. Varieties 'Belete', 'CIP-395109-34', 'Granola', 'Abadamu' and 'Agazer' had the lowest SSI values in both marketable and total tuber yields (indicating least susceptibility to stress) in the Mesino season (Fig 4-2). 'Gera', 'Granola', 'Siquare' and 'Abadamu' had the lowest values in the Belg season. These results are in agreement with previous work (Kolech et al. 2015) reporting that 'Abadamu' and 'Agazer' had good tolerance to drought. However, these local varieties had lower performance in irrigated conditions which may not be helpful in seasons with good distribution of rainfall. 'Granola' is a variety that showed both low SSI values and high yield potential, and was previously reported to have good drought tolerance (European potato variety database). In general, varieties with the lowest SSI values were early maturing ones (Table 4-1). Early maturing varieties also have the advantage of accumulating tuber yield in a relatively short period of time, thus often avoiding stress periods under field conditions (Levy, 1986; Vos and Haverkort 2007).

Harvest index differed between varieties, between seasons and between water regimes (Tables 4-2 and 4-4). Harvest index was relatively unaffected by stress in the cool, Mesino season. Wolfe (1983) also reported little HI change under drought, although maintaining or increasing HI under stress is generally considered an important trait for drought tolerance (Vos and Haverkort 2007). Growth in the warm (Belg) growing season reduced HI for all varieties, which is expected as tuberization of potato is reduced at warm temperatures (Menzel 1980). In contrast to the Mesino season, most varieties showed a decline of HI with stress in the Belg season, with the exception of 'Enat Beguaro' and 'Siquare'. However, 'Granola' had the highest HI under both irrigated (0.8) and stress (0.7) conditions in this warmer Belg season.

Drought stress can impact tuber quality and thus impact marketable yield more than total yield (Mane et al. 2008; Hassanpanah 2010; Wolfe et al. 1983). Tuber quality is also influenced by growth temperature (Struik et al. 1989). Tuber size distribution is one of the factors most determining quality of potato during drought conditions (Mackerron and Jeferries 1988). In our study all varieties had a substantial increase in unmarketable small (< 30 g) tubers in the warm (Belg) compared to the cool (Mesino) season (Table 4-5). In general, the percent of small tubers increased in the stress compared to irrigated treatment, with the exception of varieties 'Abateneh', 'CIP-395109-34', and 'Enat Beguaro' in the Mesino season. In the Belg season, only 'Enat Beguaro' showed no increase in percent small tubers under stress. But, higher incidence of tuber deformation in both water regimes showed that this variety has a low yield potential in the warmer season (Belg).

In contrast to the decrease in yield with stress, root length increased for many of the varieties under stress (Fig 4-3). An increase in partitioning of biomass to roots as opposed to leaves can improve plant water balance and is a common plant response to drought stress that may be associated with abscisic acid (ABA) precursor root signals to shoots that slow above-ground growth at low soil moisture conditions (Zhang and Davis 1990; Tardieu et al. 1996).

The SPAD readings, a green color index associated with chlorophyll per unit leaf area (Barraclough and Kyte 2001), also increased under stress for most varieties (Table 4-3). A possible explanation for higher SPAD readings under drought in our study was a higher specific leaf weight (SLW, leaf dry weight per unit leaf area) in the stress treatment for all varieties (data not shown). Smaller, thicker, higher SLW leaves under drought could have increased the density of chlorophyll per unit leaf area with the effect of increasing SPAD readings. Increases in SLW are a common drought response (Fisher and Turner 1978) that may reduce transpirational water loss and maintain

Table 4-3: Plant and root characteristics of varieties tested in two water regimes in two seasons in Ethiopia

Variety	Mesino (cool) season								Belg (warm) season							
	Pl HT (cm)		Root Length (cm)		SPAD reading		Leaf area (cm^2)		Pl HT (cm)		Root length (cm)		SPAD reading		Leaf area (cm^2)	
	I	S	I	S	I	S	I	S	I	S	I	S	I	S	I	S
Key Shull	38	36	41.3	48	26	35	5384	4818	52	45	30.7	39.2	38	43	5760	5087
Siquare	52	48	48.3	54	35	30	9425	5784	47	41	38.4	42.3	31	33	10368	7459
Agazer	59	48	36	39.5	29	30	6366	6054	-	-	-	-	-	-	-	-
Nech Abeba	66	54	43.3	47	40	41	7705	7185	63	52	41.0	44.8	42	50	6709	5654
Abadamu	59	60	43.8	51	38	39	5747	5138	60	52	40.8	43.7	43	47	8326	4811
Bulle	63	55	42.8	53.5	33	37	5607	5528	68	55	42.3	39.1	41	48	6559	5596
Enat Beguaro	51	54	41	37.5	32	31	5659	5266	48	38	28.5	34.2	39	44	6834	5303
Rejim China	69	69	47.5	43.5	34	42	5434	3896	60	49	33.0	33.1	47	49	4370	4085
Abateneh	69	63	41.7	49.5	37	40	6524	4341	-	-	-	-	-	-	-	-
Granola	44	33	34.5	43	39	37	4257	5164	41	45	27.4	38.9	42	45	4230	4202
CIP-395109.34	83	80	40.5	38.8	43	45	5516	4715	64	55	39.9	42.3	44	48	5593	4336
Sisay	55	49	49	53.8	29	31	7518	7245	52	40	42.1	45.7	40	46	5922	6243
Gera	75	75	47.8	51.8	31	32	5251	4283	67	55	40.3	38.8	44	46	5956	4104
Belete	61	51	36.8	41.8	36	31	4207	6459	-	-	-	-	-	-	-	-
Jalene	49	47	40.8	44	31	36	5535	4818	47	38	44.7	46.5	41	45	7213	6160
Mean	60	55	43.4	47.1	34.5	35.7	6009	5380	55.8	46.9	37.4	40.7	41	45	6487	5253
Treatment	**		***		*		*		***		*		***		***	
Variety	***		***		***		*		***		**		***		***	
Tre*Var	NS		NS		*		*		*		NS		NS		NS	

*, **, ***= significant at 0.05, 0.01 and 0.001 probability level, respectively. PlHT = Plant height in cm.

Table 4-4: Marketable tuber yield (MTY), total tuber yield (TTY), and harvest index (HI) at final harvest of varieties tested in two water regimes in two different seasons in Ethiopia

Variety	Mesino (cool) season						Belg (warm) season					
	MTY (g/plant)*		TTY (g/plant)		HI		MTY (g/plant)		TTY (g/plant)		HI	
	I	S	I	S	I	S	I	S	I	S	I	S
Key Shull	480 bcde	343 bcd	569 cd	452 ab	0.8	0.8	216 cd	54 cd	503 ab	296 ab	0.5	0.6
Siquare	507 bcde	378 abcd	581 bcd	440 bc	0.8	0.8	32 g	11 cd	241 f	139 e	0.4	0.4
Agazer	411 def	306 cd	581 bcd	511 ab	0.8	0.8	-	-	-	-	-	-
Nech Abeba	519 abcde	383 abcd	635 abcd	524 ab	0.8	0.8	167 def	21 cd	420 bc	211 cd	0.6	0.5
Abadamu	609 abc	486 ab	647 abc	531 ab	0.9	0.8	353 ab	135 b	387 cd	202 cde	0.7	0.5
Bulle	466 bcde	238 d	612 abcd	462 ab	0.9	0.8	77 efg	17 cd	367 cde	200 cde	0.6	0.4
Enat Beguaro	407 ef	287 cd	609 abcd	277 d	0.9	0.8	44 g	0 d	421 bcd	226 c	0.5	0.5
Rejim China	563 abcde	408 abcd	668 abc	569 ab	0.8	0.8	59 fg	9 cd	342 de	141 e	0.5	0.3
Abateneh	263 f	241 d	392 e	303 d	0.7	0.7	-	-	-	-	-	-
Granola	575 abcd	437 abc	625 abcd	511 ab	0.9	0.9	434 a	209 a	536 a	315 a	0.8	0.7
CIP-395109.34	643 ab	545 a	702 ab	581 a	0.8	0.7	281 bc	77 bc	366 cde	191 cde	0.6	0.5
Sisay	592 abcd	404 abcd	607 abcd	490 ab	0.8	0.8	188 cde	31 cd	358 cde	189 cde	0.7	0.5
Gera	694 a	400 abcd	732 a	465 ab	0.8	0.8	212 cd	127 b	383 cd	222 c	0.6	0.5
Belete	440 cdef	371 abcd	515 de	470 ab	0.8	0.8	-	-	-	-	-	-
Jalene	619 abc	352 bcd	669 abc	564 ab	0.8	0.8	132 defg	28 cd	307 ef	149 de	0.5	0.4
Mean	519	372	610	477	0.8	0.8	175	58	385	209	0.6	0.5
Variety	***		***		***		***		***		***	
Treatment	***		***		***		***		***		***	
Variety *treat	NS		NS		*		**		NS		NS	

MTY= Marketable tuber yield; TTY = Total tuber yield; HI = Harvest index, *varieties with similar letters are not significantly different at $P<0.05$. *, **, ***= significant at 0.05, 0.01 and 0.001 probability level, respectively.

Table 4-5: Percent unmarketable small sized (<30 gm), deformed, and green tubers

Variety	Mesino						Belg					
	% small tubers		% weight of deformed tubers		% weight of green tubers		% small tubers		% weight of deformed tubers		% weight of green tubers	
	I	S	I	S	I	S	I	S	I	S	I	S
Key Shull	15.4	25.9	0	0	0	0	89.6	100	15	07	06	16
Siquare	12.9	14.1	0	0	0	0	48.5	84.2	00	02	29	11
Agazer	31.6	40.0	0	0	0	0	-	-	-	-		-
Nech Abeba	22.9	26.8	0	0	0	0	83.4	93.3	00	04	04	18
Abadamu	5.5	8.3	0	0	0	0	79.4	92.9	06	11	16	40
Bulle	23.6	48.8	0	0	0	0	23.1	61.4	10	00	08	07
Enat Beguaro	33.4	30.7	0	0	0	0	45.5	45.2	29	09	09	08
Rejim China	15.6	30.5	0	0	0	0	87.8	94.4	00	20	05	08
Abateneh	38.8	23.0	0	0	0	0	-	-	-	-	-	-
Granola	8.1	14.9	0	0	0	0	58.8	80.8	03	00	01	01
CIP-395109.34	8.3	8.1	0	0	0	0	57.6	83.4	00	03	00	00
Sisay	2.3	18.3	0	0	0	0	8.6	34.0	13	13	08	05
Gera	5.1	13.1	0	0	0	0	18.9	33.3	04	07	00	00
Belete	18.5	21.3	0	0	0	0	-	-	-	-	-	-
Jalene	7.6	38.6	0	0	0	0	58.2	89.8	10	02	15	04
Mean	16.3	23.9	0	0	0	0	54.1	74.4	07	07	08	10

photosynthetic capacity per unit leaf area by packing more chlorophyll and photosynthetic enzymes into a given leaf area exposed to sunlight. However, in our study total leaf area per plant was reduced under stress, thus constraining photosynthetic capacity and growth at the whole plant level.

4.1.8 Yield determining traits for water stress tolerance

Traits conferring yield stability under drought might include an array of morphological, physiological and biochemical adaptations (Schafleitner et al. 2007; Monneveux et al. 2013). We evaluated the correlation of several morphological and growth traits in relation to marketable and total tuber yield under water stress conditions for each growing season (Table 4-6). We found a positive and statistically significant ($P<0.05$) correlation between HI and marketable tuber yield in both the Mesino and Belg seasons ($r = 0.53$ and 0.56, respectively). This corroborates prior studies documenting the importance of maintaining HI as an adaptive trait for water stress conditions (Monneveux et al. 2013; Lahlou et al. 2003; Wolfe et al. 1983; Van Loon 1981). Total stem biomass was negatively correlated with HI ($r = -0.72$ and -0.51 in Mesino and Belg seasons, respectively), and stem biomass was also negatively correlated with marketable tuber yield in both seasons, but with smaller r values ($r = -0.10$ and -0.37 in Mesino and Belg seasons, respectively). Leaf area ratio (LAR = leaf area/total biomass) was negatively correlated with marketable tuber yield ($r = -0.37$ for both Mesino and Belg seasons). A high LAR reflects a lower production efficiency per unit leaf area, and high leaf area can exacerbate water stress because of higher transpirational water loss.

We found that the average increase in root length under stress was more than 3 cm in both seasons (Table 4-3). Deeper roots can improve plant access to water and minimize yield decline in drought conditions, and thus is a beneficial trait for drought tolerance (Lahlou and Lendent 2005; Schafleitner et al. 2007). Jefferies (1993), in a modeling experiment, showed that an increase in rooting depth improves yield under drought conditions. In our study we observed differences between varieties in the magnitude of the root length difference between irrigated and stressed treatments (Fig. 4-3), with ‘Abateneh’, ‘Bulle’, and ‘Granola’ having the greatest root response to water stress in the Mesino season, while ‘Abadamu’, ‘Granola’, ‘Jalene’, and ‘Siquare’ had the most response in the Belg season.

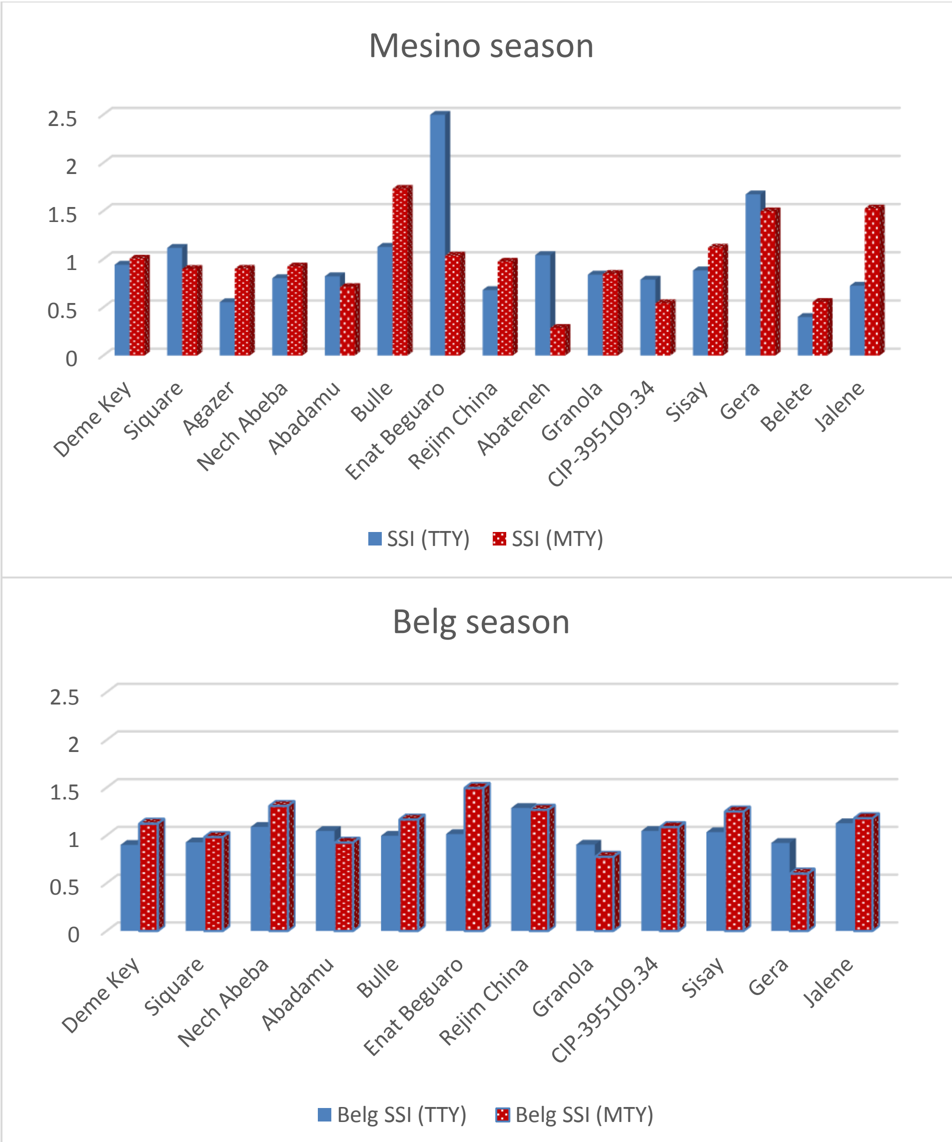

Figure 4-2: Water Stress Index for total tuber yield (TTY) and marketable tuber yield (MTY) of varieties tested for Mesino and Belg seasons

It is important to keep in mind that under field conditions with unreliable rainfall, early maturing (i.e., short growing season) varieties may complete their life cycle and avoid or escape drought compared to later maturing varieties. Thus, early maturity per se can be a desirable trait under water stress, even if a variety does not have particularly high yield potential and does not possess traits conferring drought tolerance. Thus, while varieties such as 'Agazer', were not the top performers under water stress as imposed in this study, they may have a niche in growing seasons that are abbreviated due to drought. ‘Agazer’ was identified in a grower survey as preferred in drought conditions (Kolech et al. 2015). ‘Granola’ and ‘CIP-395109.34’ were varieties with the advantage of being both early maturing and also exhibiting tolerance to drought based on marketable yields and related traits.

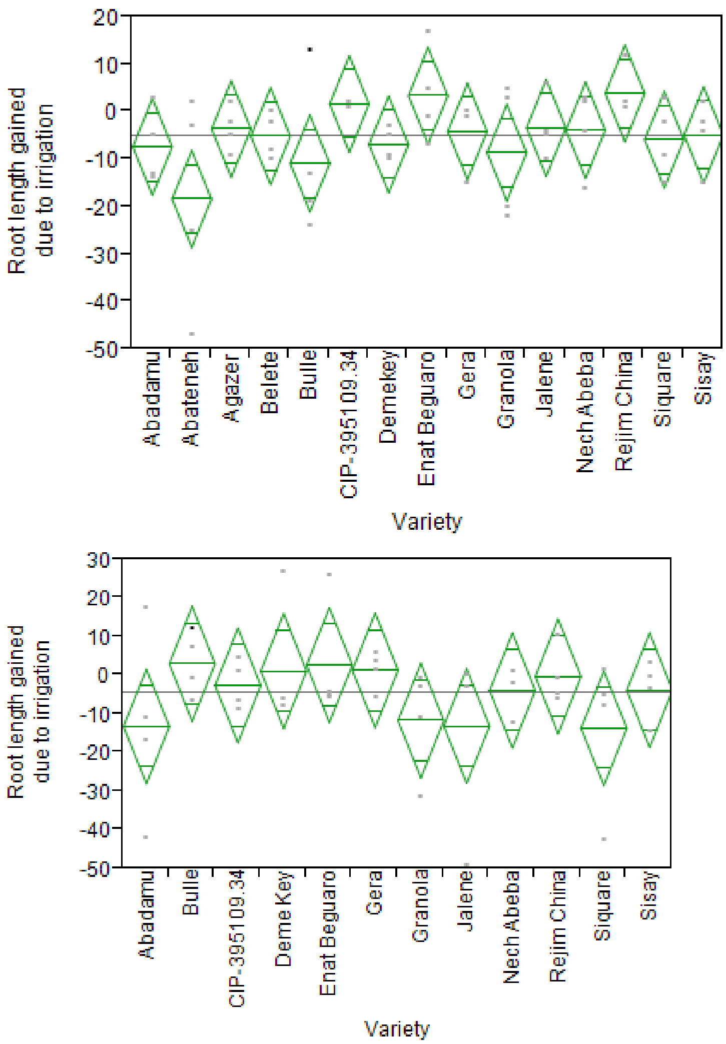

Figure 4-3: Increment of root length due to irrigation across varieties in Mesino (above) and Belg (below) seasons

Table 4-6: Pairwise Correlation between marketable tuber yield and other important traits, during Mesino (above diagonal) and Belg (below diagonal) season under stress conditions

	Stem wt	Stem wt/ leaf wt	AGB	SLW	BGB/ AGB	SPAD	MTY	TTY	LAR	HI
Stem wt	1	0.82	0.78	-0.01	-0.29	0.42	-0.10	-0.28	-0.07	-0.72
Stem wt./leaf wt	0.73	1	0.46	-0.01	-0.27	0.34	-0.17	-0.02	-0.20	-0.51
AGB	0.81	0.22	1	0.04	-0.58	0.22	-0.07	-0.10	-0.21	-0.85
SLW	0.33	0.33	0.24	1	0.07	-0.12	0.03	-0.01	-0.22	0.04
BGB/AGB	-0.59	-0.31	-0.64	-0.15	1	0.20	0.16	0.22	-0.01	0.54
SPAD	0.18	0.02	0.26	0.09	-0.06	1	0.12	0.14	-0.20	-0.08
MTY	-0.37	0.05	-0.53	0.09	0.44	0.06	1	0.73	-0.37	0.53
TTY	-0.50	-0.13	-0.61	-0.02	0.61	0.09	0.61	1	-0.53	0.33
LAR	-0.18	-0.28	-0.06	-0.71	-0.04	-0.27	-0.37	-0.34	1	0.18
HI	-0.51	-0.09	-0.62	-0.22	0.46	0.06	0.56	0.78	-0.33	1

Stem wt/leaf wt= the ratio of stem dry weight over leaf dry weight; AGB= above ground biomass (g); SLW= specific leaf weight; BGB/AGB= the ratio between below ground and above ground biomass; MTY= marketable tuber yield per plant (g); TTY= total tuber yield per plant (g); LAR= leaf area ratio; HI= harvest index.

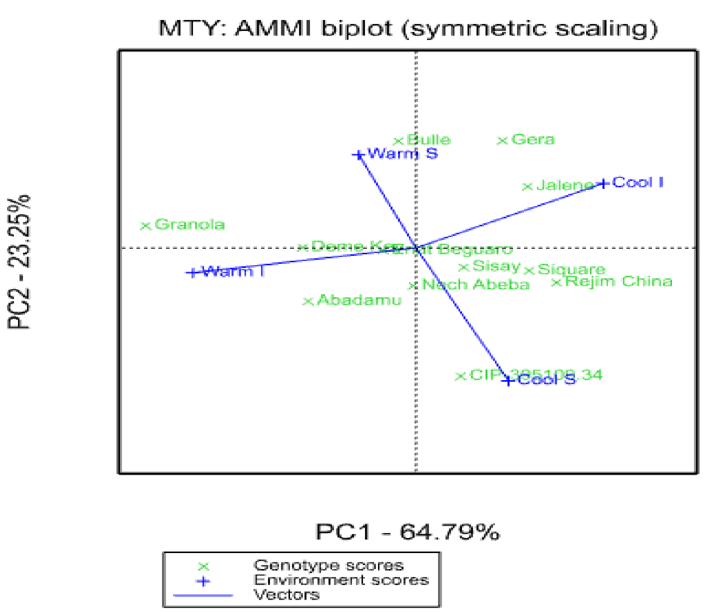

Figure 4-4: An AMMI (Additive Main Effects and Multiplicative Interaction) biplot reflecting the relationship of varieties and environment (seasons and water regimes)

4.4 Summary

Indicator traits are useful to discriminate varieties for drought stress tolerance. In the present study, those varieties that had high yield potential and stability under both irrigated and stress conditions, maintained HI under stress, increased root length under stress, and had relatively low LAR under stress, were those that had the highest marketable yields and/or least marketable yield reduction under stress. Early maturity is also recognized as an important trait for growing seasons constrained by drought. In our study, varieties with highest yield potential under both irrigated and stress conditions were 'CIP-395109.34' and 'Gera' in the Mesino (cool) season, and 'Abadamu' and 'Granola' in the Belg (warm) season. Stress susceptibility index, which focuses on percent yield decline under stress relative to other varieties, was lowest (best) for 'Belete', 'CIP-395109.34', 'Granola', 'Abadamu', and 'Agazer' in the Mesino season, and 'Gera', 'Granola', 'Siquare', and 'Abadamu' in the Belg season. 'Granola' stood out as a variety with wide adaptability and both high yield potential and low SSI values.

AMMI biplot analysis also showed that most of the local varieties, even those that are low yielding, are close to the origin (Fig. 4-4). That suggests that these varieties are stable under a range of water availability and growth temperature conditions even if there is variability in weather conditions. The AMMI plot reflects that 'Granola' performed well in both water regimes but was better adapted to the warm growing season than that of the cool season. 'Jalene' (new CIP variety) and most of the local varieties were well adapted to the cool growing season in both water regimes. 'Abadamu' is the only local variety that performed better in the Belg season while all of the late maturing local varieties have higher yield loss due to water deficit stress as indicated by a high stress susceptibility index in this season.

This study was focused on identifying genotypic variation in marketable yield under water stress and quantifying plant traits associated with drought tolerance under controlled water management conditions. Wishart et al. (2013) found consistent results for many traits including root traits in pot and field experiments, but we recognize that this is not always the case (Mokany and Ash 2008), and a next phase will be an evaluation of water stress responses under field conditions.

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CHAPTER 5: **IDENTIFICATION OF FARMER PRIORITIES IN POTATO PRODUCTION THROUGH PARTICIPATORY VARIETY SELECTION**

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Abstract

A substantial number of farmers in northwest Ethiopia grow potato in the dry season ("Belmehr", March to August) when rainfall is not dependable for the growth of the crop, resulting in lower yield. Ethiopian Agricultural Research Institutes have tried to change the situation by releasing new late blight tolerant varieties that potentially could allow for production of the crop in the rainy season ("Meher", May to October). Despite these efforts, the majority of the farmers still grow potato in the Belmehr season using older, local varieties. Cognizant of this fact, this study aimed to characterize the major potato production problems in the two seasons, to identify the traits that farmers consider most important when selecting potato varieties, and to assess the performance of widely grown local as well as newly developed varieties. The study was conducted at sites representing two major agroecological zones in northwest Ethiopia and during both production seasons using 12 varieties (9 local and 3 new) with a 'participatory variety selection' approach. During the Belmehr season, erratic rainfall resulted in low yield and lower average tuber weight. By contrast, in the Meher season, late blight, desiccating wind and severe precipitation, including hail, limited production. These factors were important in both agroecological zones, with varying degrees of importance. Twenty-three traits were found to influence the varieties that farmers selected, with the degree of importance of each trait differing between agroecological zones and

gender groups. Some local varieties yielded as well as new varieties in both seasons. Overall, we found participatory variety selection to be an effective approach for identifying factors important for the adoption of potato varieties, including factors that may not be addressed in conventional potato breeding programs.

Key words: Ethiopia; Growing season; Agroecological zones; Gender; Variety; Variety traits

5.1 Introduction

Potato (*Solanum tuberosum* L.) is an important food security crop in Ethiopia that is grown in widely differing agroecological zones and growing seasons. The country has four distinct seasons (Belg, Meher, Belmehr and Mesino) for production and these have been described by a number of workers (Woldegiorgis et al. 2008; Tesfaye et al. 2008; Yazie et al. 2009; Gildemacher et al. 2009a; Kolech et al. 2015). There is some confusion in the literature about seasons of potato production due to a lack of distinction between the Belmehr and Meher seasons (Kolech et al. 2015). The descriptions of each season are as follows.

The Belg season, also called the short rainy season, starts in January and continues to May or June. This season is commonly used for potato production in Oromia (East and West Arsi), in the Southern Nations, Nationalities and Peoples' State (SNNP) and in some areas of central Ethiopia. Late blight pressure is less problematic in the Belg season because of relatively low rainfall and humidity (Bekele and Eshetu, 2008). Moreover, Belg is a favorable season for farmers to get good market prices because of a cultural factor; this season coincides with a fasting period where participants avoid meat and milk products.

The Meher season, also called the rainy season, starts in May or June and ends in October. Late blight is the major potato production challenge in this season and losses to late blight are thought to be responsible for some farmers shifting production to the Belg season (Bekele and Eshetu, 2008). Potato production in Meher is common in Shashemene and surrounding areas (Tesfaye et al. 2008; Kolech et al. 2015). Ethiopian Research Institutes are working to expand potato production into the Meher season by developing late blight resistant and early maturing varieties.

The Belmehr season overlaps the Belg and the Meher seasons. Belmehr potato production starts in March or April and lasts into August. Most potato production in northwest Ethiopia takes place during Belmehr. Potato is the only crop grown during this season and it is a primary source of food for residents of the highland during July and August, filling a critical gap. Starting in the middle of this season, farmers in the northwest start to sow other crops under the potato crop.

The Mesino season, also called the residual production season, starts in September and continues through December or January. It is a cropping season for residual potato and barley production immediately following the main rainy season. Some farmers in the moist agroecological zone of northwest Ethiopia grow potato in this season, however, yield is very low (Yazie et al. 2009; Kolech et al. 2015).

Unlike other major crops, most potato production (more than 62% of 179,000 ha) takes place during Belg and Belmehr seasons (CSA 2014). The productivity in these seasons is reportedly very low, only 7.3 ton/ha, as the moisture conditions are inadequate, especially in the Belmehr season. Different reasons have been suggested as to why farmers grow potato in the Belmehr season despite the known challenges and lower yields. One is related to filling the gap in food availability during the "hungry months" of July and August (Woldegiorgis et al. 2008; Woldegiorgis et al.

2013). Another reason to grow during this season is to avoid the late blight damage seen in the main (rainy) season (Bekele and Eshetu, 2008; Woldegiorgis et al. 2008). A third reason is a lack of seed of well-adapted, late blight-resistant varieties for production during the main season.

The Ethiopian agricultural research system, including federal and regional research institutes as well as universities, has allocated considerable resources to the development and dissemination of improved potato varieties to increase potato production and productivity by small farmers. The variety improvement program utilizes germplasm sourced mainly from the International Potato Center (CIP) (Woldegiorgis et al. 2008) and focuses selection on yield potential and late blight resistance. Since 1975, the Ethiopian agricultural research institutes, Haramaya University and one private seed company (SolaGrow) have developed 31 potato varieties (MOA 2013), mainly for production in the Meher season. Potato production has increased during the Meher season as a result of these varieties, especially in the areas of Guraghe, West Shewa and North Shewa (Kolech et al. 2015). Success has been especially good in areas where potato production only began recently.

Although the improved varieties have been reported to be high yielding and resistant to late blight, their adoption by farmers has been low in most areas where the new varieties have been disseminated (Abebe et al. 2013; Woldegiorgis, 2013). As a result, only a few of the new varieties are grown (Woldegiorgis 2013). Hence, the majority of smallholder farmers still grow their own local potato varieties (Gildemacher, et al. 2009b, Hirpa et al. 2010) and most farmers in northwest Ethiopia still grow potato in the dry season (CSA 2014).

Three overlapping factors may account for the limited adoption of new varieties. The first is that there may be a mismatch between the goals of potato breeders and the needs and preferences of farmers. Farmers need multiple traits in their potatoes to fulfill multiple needs, and they may not adopt a new variety that performs well for some traits but poorly for others (Bellon 2002). A second factor pertains to subjective traits such as taste, culinary quality, and color. Recognizing and breeding for subjective traits is a difficult challenge for breeders operating without close collaboration with farmers and social scientists (Almekinders and Elings 2001; Bellon 2002). A third factor is related to storability, which varies between varieties, environments and agronomic practices. It is difficult for breeders to evaluate storage properties for so many possible conditions.

An additional concern is that local varieties are thought to have low yield potential and to be susceptible to late blight (Kidane-Mariam 1980; Lemaga 1983). Because of this, local varieties have received little attention in potato breeding efforts in Ethiopia. There has, however, never been an experimental confirmation of the low yield of local varieties when starting with disease-free seed. Yield trials in Ethiopia often include local varieties as a check when evaluating new germplasm. In such trials, the seed of the new germplasm is usually known to be disease-free, while the health status of the seed potatoes of the local varieties is almost invariably unknown.

To understand the real cause(s) of low adoption of new varieties, which would in turn inform future variety development efforts in Ethiopia, it is important to work directly with farmers and use healthy seed in all trials. Participatory variety selection (PVS) brings breeders, farmers and social scientists together to identify gaps in the crop adoption process and to target and prioritize traits of importance (Almekinders and Elings 2001; Bellon 2002). PVS is a widely used approach that provides farmers with a choice of genotypes (varieties and advanced materials) that can be evaluated under social and agroecological conditions of relevance to the farmers (Weltzien et al. 2000; Almekinders and Elings 2001; Gibson et al. 2008). PVS has proven helpful when breeders want to improve upon the rate of improved variety adoption (Almekinders and Elings 2001;

Mulatu and Zelleke 2002; Bellon 2002; Danial et al. 2007), and for ascertaining gender differences in selection criteria (Bellon, 2002; Vom Brocke et al. 2010).

The objectives of this study were: 1) to characterize major production challenges in two growing seasons and in two major agroecological zones in northwest Ethiopia; 2) to identify farmer variety selection criteria and assess their relative importance among gender groups and agroecological zones using a PVS approach; 3) to assess specific characteristics of major local and new varieties as perceived by farmers; and 4) to measure the agronomic performance of local varieties compared to the most successful new cultivars using breeders' selection criteria (tuber yield, late blight resistance and tolerance to drought and other major abiotic stresses).

5.2 Material and Methods

5.2.1 Study locations, planting seasons and varieties

A PVS approach was adapted from the guidelines of the Africa Rice Center (Africa Rice Center, 2010), and a design was established to enable breeders and social scientists to effectively collect data on important parameters with the participation and cooperation of farmers.

Six major potato-growing districts in Ethiopia were surveyed during 2012 and 2014 to assess the diversity of varieties grown by farmers (Kolech et al. 2015). Based on this survey, two districts (Yilmana and Laigaint) were selected in northwest Ethiopia representing different agroecological conditions, market outlets and food security levels, but sharing similar farming systems (the same growing seasons and, the same crops such as barley, potato and a few legumes). The district of Yilmana (2800 m, located at 11º16'N latitude and 37º28' E longitude) has a wet agroecology while Laigaint (3100 m, located at 11º43' N latitude and 38º28' E longitude) represents dry agroecology with less dependable rainfall. Farmers in Laigaint are food insecure and potato is the primary source of food. In both districts, potatoes are planted in Belmehr and Meher seasons. The average five-year rainfall distribution for the two locations is shown in Fig 5-1. Twelve potato varieties (9 local and 3 new varieties) with diverse traits (early and late maturing, white, purple and red color tubers, short and tall plants, etc.) were included in the study. The local varieties were collected from major potato producing areas of Ethiopia during our survey in 2012, tested for plant pathogens and multiplied in vitro to produce seed. The new varieties were developed and released by the Ethiopian Agricultural Research Institutes in collaboration with the International Potato Center (CIP). The local and new varieties were planted in four environments (two districts * two seasons). A description of varieties included in the study is shown in Table 5-1.

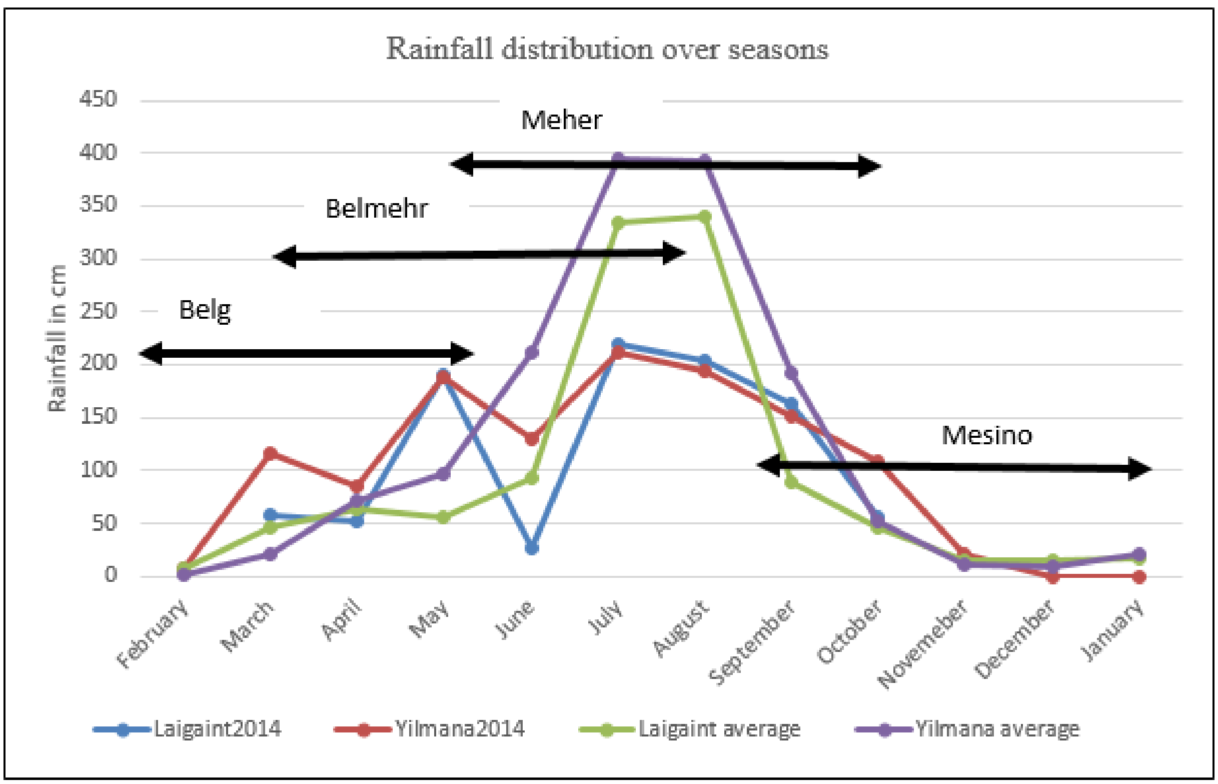


Figure 5-1: Annual rainfall for the study sites in 2014 and the last five-year average during four seasons

Table 5-1: Varieties included in Participatory Variety Selection at Laigaint and Yilmana in 2014

Variety	Origin[1]	Maturity and other characteristics[2]	Where produced
Enat Beguaro	Local	Medium late, no flowering, high number of white tubers	Sinan District (Amhara region)
Abadamu	Local	Medium early, late flowering, market desired tuber size	Quarit District (Amhara region)
Siquare	Local	Early, round red tubers, widely grown	Mid to cool highlands of northwest Ethiopia (Amhara region)
Feleke	Local	Very late, late flowering, round white tubers	Chencha District (SNNP region)
Bulle Local	Local	Medium early, early flowering, round purple tubers	Kofele district (Oromia region)
Nech Abeba	Local	Medium early, round white tubers	Shashemene and surrounding areas (SNNP and Oromia regions)
Key Shull	Local	Very early, early flowering, oval tubers	Shasho District (SNNP region)
Rejim China	Local	Late, tall plants, white tubers with pink pigment around the eyes	Kofele District (Oromia region)
Abalo	Local	Late maturing, tubers noted for flavor but not attractive, widely grown	Cool highlands in northwest Ethiopia
Gera	New	Early maturing, round tubers with deep eyes	Reported to be well adapted to dry areas above 2700 m.
Jalene	New	Medium early, early flowering, russet tubers	Reported as widely adapted variety in Ethiopia
Belete	New	Early maturing, high yielding, late blight tolerant	Reported as widely adapted

[1] Origin refers to distinguishing between locally cultivated varieties, 'Local', versus those more recently introduced varieties, 'New'.

[2] Varieties were grouped into six maturity classes; very early (<90 days), early (90-100), medium early (101-110), medium late (111-120), late (121-130) and very late (>130 days) based on Belmehr season production.

5.2.2 Design of the experiment and field management

The sites for the experiment were selected as representative farms in terms of fertility status, soil type and topography. Before planting, soil testing was done in each of the two sites representing the two districts. Three soil samples were collected at each site using an auger to a depth of 20 cm. Three samples from each site were bulked together and immediately sent to the national soil laboratory in Addis Ababa for analysis.

In order to assess the performance of varieties, plots were laid out in a randomized complete block design with three replications of 9 m^2 plots for each variety in each district and season. The field trials were managed jointly by researchers and farmers. Animal traction was used to plant the varieties during Belmehr season for both locations; ridging (hilling) was done after the plants emerged. For Meher season production, however, ridging was done at planting as recommended by Gebremedhin et al. (2008). Ridomil was sprayed at the rate of 4 kg/ha for late blight protection during the Meher season, twice at Laigaint and once at Yilmana.

5.2.3 Selection of farmers and data collection

Two farmers' research groups (FRGs) consisting of 7 women and 28 men at Yilmana (total of 35 farmers) and 17 women and 22 men at Laigaint (total of 39 farmers) were organized. The selection of farmers was village based (living in the same village) and participation was voluntary. The groups evaluated varieties at the time of flowering, harvest and post-harvest following strategies described in the Technician's Manual for participatory variety selection of rice (Africa Rice Center 2010). At each location the harvested tubers were stored in a relatively cool, dark place within the home of one of the FRG members, and assessment of storage quality was made after 3 months of storage. Data on the socioeconomic status of the FRG members was collected, and during each field visit, FRG members were separated by gender and asked to rate the varieties and indicate the reasons why they chose them.

In addition to farmers' evaluations, data were collected by the research team on yield, date of flowering and maturity and other marketable traits of the varieties as well as their response to late blight, wind and hail damage.

5.2.4 Data analysis

Average tuber weight, marketable tuber yield (excluding tubers that were less than 30 g, diseased or deformed) and total tuber yield in each environment (combined among seasons and locations) were calculated and analysis of variance of the varieties computed using JMP software (JMP PRO 10.0.2). Analysis of the trait ratings was also computed using this software. An Additive Main effects and Multiplicative Interaction (AMMI) model was used to partition variety by environment interaction and to construct biplots. AMMI analysis was computed using GenStat software (GenStat 2013). Descriptive statistics and frequencies were also calculated to obtain the highest-ranking traits between gender groups.

5.3 Results

5.2.5 Grower-identified factors affecting potato production

Several factors that limit production were identified by farmers in both districts and cropping seasons. Growers were asked to rank the factors they identified on a scale of 1 ("less important") to 3 ("very important"). Generally, farmers cited 8 factors as "very important" (Table 5-2), with late blight rated as "very important" by nearly all of the farmers in both districts. However, the significance and extent of other problems differed between districts and cropping seasons. Although drought (unreliable and erratic rainfall) is a very important parameter for the Belmehr season in both districts, it was rated higher at Laigaint than Yilmana. Other factors rated as "very important" by the majority of the farmers in a given district were desiccating wind and low soil fertility at Laigaint and severe precipitation and hail damage at Yilmana. In Yilmana, the crop was exposed to hail three times in the Meher season, resulting in the poor performance of most varieties. At Laigaint during the Meher season, desiccating wind starting in September coupled with terminal moisture stress resulted in lodging and drying of the plants. Tuber spoilage in the soil and in storage as well as small tuber size (defined as not fit for market demand or less than 30 g weight) were also major problems in both locations. Bird damage on tubers is a common problem during planting and harvesting at Laigaint. We also observed red ants during harvest of tubers and took weight measurement of the affected tubers. The ratio of the weight of affected tubers in relation to total tuber weight in each variety showed a tuber quality loss up to 29% due to red ant damage in the Meher season at Laigaint.

Table 5-2: Production problems that farmers rated as “very important” in two locations

Production challenges*	**Target seasons**	**Percent of farmers rating production problems as "very important"**	
		Laigaint	Yilmana
Bird Damage	Meher and Belmehr	45.9	14.7
Drought	Both, mainly Belmehr	100.0	85.3
Unmarketable tuber size (for market purpose)	Both, mainly Belmehr	62.2	67.6
Desiccating wind	Both, mainly Meher	78.4	NL
Heavy rainfall load & Hail damage	Meher	NL	70.6
Late blight	Both, mainly Meher	94.6	97.1
Low soil fertility	Both, mainly Belmehr	75.7	50.0
Tuber spoilage	Meher and Belmehr	73.0	70.6

NL= not listed as a production problem; “low importance” and “very important” corresponded to 1 and 3, respectively on a scale of 1 to 3.

An AMMI model based on total tuber yield shows distinct clustering of the four environments (Meher and Belmehr seasons in Laigaint and Yilmana districts) (Fig 5-2). Two environments (Meher at Yilmana and Belmehr at Laigaint) on the AMMI plot were more closely related to each other than the rest of the environments. This suggests that challenges caused by abiotic stresses were equally important in these environments. Most early maturing varieties clustered on the Meher season quadrant and close to the origin indicating these varieties are more suitable for

Meher season production in both districts. In contrast, late maturing varieties are far from the origin but grouped on the Belmehr season in one of the districts indicating that these varieties are better adapted to Belmehr season production.

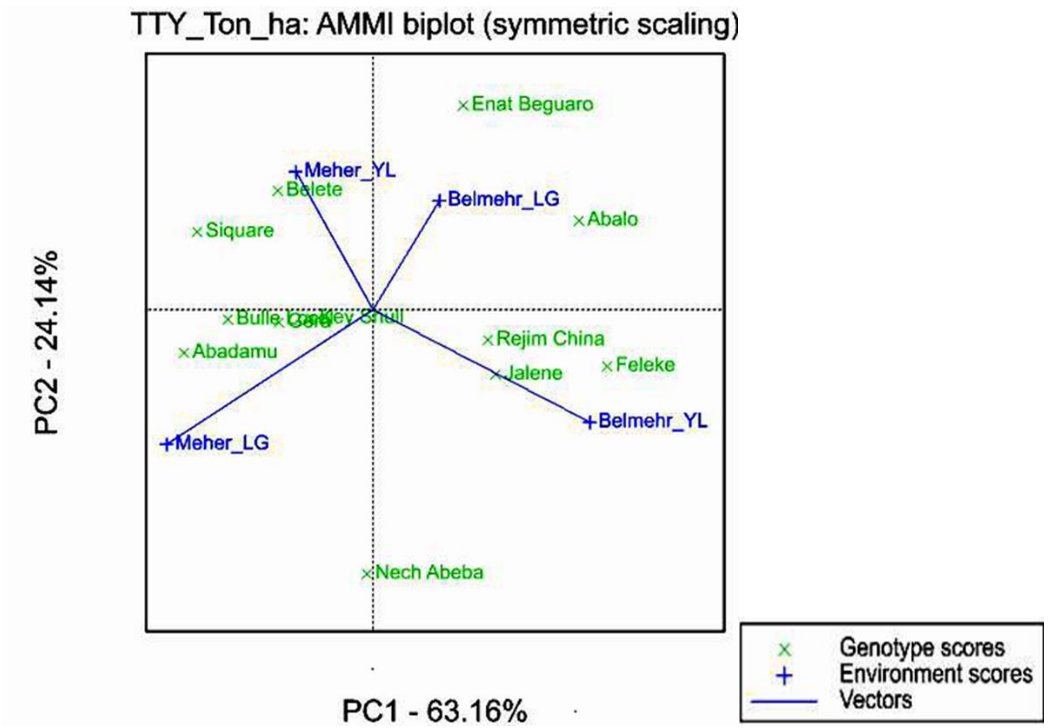


Figure 5-2: An AMMI biplot showing the relationship of variety and environment in terms of total tuber yield (tons/ha).

Soil sample testing

The result of the soil analysis is shown in Table 5-3. The data shows that an important nutrient, potassium, is far below optimum in both sites. Moreover, the organic carbon content and total available nitrogen are at levels below those recommended for good crop growth, indicating soil fertility and possibly water holding capacity and drainage constraints to optimum productivity at both sites. For phosphorus, the soil in Laigaint was much lower than that of Yilmana. Moreover, the soil in Laigaint is more acidic than that of Yilmana.

Table 5-3: The availability of different soil nutrients based on soil testing

Site	pH	K (Cmol/kg soil)	CEC	T.N (%)	O.C (%)	Fe (PPM)	Zn (PPM)	Av.P (PPM)
Yilmana	6.85	3.08	43.07	0.21	2.55	30.47	56.54	31.14
Laigaint	5.67	ND	25.91	0.22	2.06	51.72	22.49	7.19
Low level	5.5[a]	<60[a]	5[b]		3[b]	< 3[b]	< 1[b]	<7[a]

ND indicates results with less than methods detection limit; K= Potassium; CEC= Cation Exchange capacity, T.N= Total Nitrogen; O.C= Organic Carbon content; Fe= Iron; Zn= Zinc; Av.P= Available phosphorus.

[a]= based on the minimum level standards of Colorado State University, http://www.ext.colostate.edu/pubs/crops/00541.html, accessed on 6/4/2015.
[b]= based on the minimum level standards of the University of Maine, http://anlab.umesci.maine.edu/soillab_files/under/com, accessed on 6/4/2015.

5.2.6 Potato traits important to farmers by agroecological zone and gender

Potato traits important to farmers were revealed by the responses farmers gave in the process of selecting varieties. Twenty-three traits were identified during farmers' evaluation of varieties at flowering, harvest, and in storage in both seasons and districts (Table 5-4 and 5-5). At the pre-flowering and flowering stages, farmers were more concerned about morphological characteristics such as ground foliage cover, leaf size, stem thickness and leaf strength, flowering status, late blight resistance and others. At harvest, growers were more concerned about tuber yield and tuber characteristics such as tuber size, tuber number, tolerance to lodging due to wind at Laigaint and tolerance to hail damage at Yilmana, time to maturity, and other factors. After harvest, the farmers were more concerned with taste, tuber storage quality and tuber sprout number.

The degree of importance of these traits differed between districts and gender groups. Traits such as drought tolerance, adaptation to soil with low fertility, long stolons, tolerance to bird damage and suitability for multiple harvesting received significantly higher ratings at Laigaint than at Yilmana (Table 5-4). At Yilmana, however, stew quality and market demand were of greater concern than at Laigaint. This correlates with market access; almost all of the farmers in Yilmana sold their produce in markets at least once that year, while only 33.3% of the farmers did so at Laigaint.

A comparison of rankings by men and women shows a significant difference for a few traits at Laigaint but not at Yilmana (Table 5-4), but on the whole concerns for most traits do not differ by gender. In Laigaint, low soil fertility and market demand are more important concerns for men than women while a long stolon (which is related to the ability to harvest the crop two or more times in the same season) is of greater concern to women than to men. Food insecurity is a common problem in Laigaint due to frequent drought. Women are more concerned with filling the food security gap and want varieties that have a slow tuber-bulking rate. Men are more concerned with market demand and prefer the most profitable varieties to resolve their immediate cash problems.

5.2.7 Farmers' perception of characteristics of the studied varieties

Specific variety characteristics that farmers pay attention to during flowering, harvesting and after 3 months of storage are shown in Table 5-6. All of the southern Ethiopian (SNNP and Oromia) local varieties, as well as one new variety ('Jalene') were found to have short storability. Farmers' ratings of storability after three months storage are shown in Fig 5-3. Two of the new varieties ('Belete' and 'Gera') and the local variety 'Siquare' have intermediate storage life although farmers complained that 'Belete' does not store well in typical 'in-home' storage. 'Abalo' and 'Abadamu' (local varieties from northwest Ethiopia) have excellent storability. Varieties also differed with regard to suitability for boiling and stew making quality. 'Abalo' has excellent taste after boiling and is good for making stew, while 'Abadamu' is ranked the lowest for boiling but can be used for stew. 'Belete' has excellent stew quality but is not appreciated as a boiling potato.

Varieties with good physical appearance and desirable tuber size meet the demands of markets in Yilmana and surrounding areas. For purposes of marketing, tubers of 'Abalo' are not considered sufficiently attractive. Adequate tuber size is related to marketability of their produce, and this may affect grower decisions, as the tubers produced in the Belmehr season are typically small and do not attract good market prices. Varieties such as 'Bulle Local', 'Key Abeba', 'Enat Beguaro' and 'Rejim China' gave the lowest average tuber weight.

The relative importance of long stolons, a trait that facilitates sequential harvests of the crop in a single growing season, differed between districts. Multiple harvests are only practiced during the Belmehr season and with late maturing varieties. Varieties with long and numerous stolons are also good for combating bird damage since birds cannot access the tubers easily.

Farmers in both districts grow varieties with distinct characteristics. The degree to which farmers consider each of these traits to be important in four widely grown varieties is summarized in Table 5-7. The four varieties were significantly different from each other in 22 of the 23 traits evaluated. Based on the nine most important traits common to both districts (considered "very important" by more than 70% of the farmers), 'Abalo', 'Belete' and 'Siquare' have 9, 7 and 5 important traits, respectively, while 'Jalene' has the lowest (3 traits). Moreover, 'Abalo' has the additional trait advantage at Laigaint of its adaptation for poor soil fertility while the rest of the varieties have the additional advantage of market demand at Yilmana.

Table 5-4: Average ratings of potato variety trait importance by district and gender.

	Laigaint			Yilmana			Location mean		
Traits	**Male**	**Female**	**Prob>X^2**†	**Male**	**Female**	**Prob>X^2**	**Laigaint**	**Yilmana**	**Prob>X^2**
Biotic and abiotic tolerance									
Drought tolerance	3.00	3.00	NS	2.79	3.00	NS	3.00	2.85	0.005
Low soil fertility adaptation	2.90	2.36	0.029	2.43	2.57	NS	2.70	2.47	0.038
Bird damage tolerance	2.45	2.36	NS	1.54	2.00	NS	2.41	1.65	0.000
Late blight resistance	2.90	3.00	NS	2.93	3.00	NS	2.95	2.94	NS
Wind and hail damage tolerance	2.65	2.86	NS	2.61	2.86	NS	2.76	2.68	NS
Tuber spoilage tolerance	2.65	2.57	NS	2.57	2.86	NS	2.65	2.65	NS
Agronomic traits									
Long shelf life	2.95	3.00	NS	2.93	3.00	NS	2.97	2.94	NS
Long root and stolon system	2.10	2.21	0.047	1.46	1.29	NS	2.16	1.38	0.000
Large plant height	1.75	1.71	NS	1.32	1.14	NS	1.78	1.26	0.001
Large leaves	2.25	2.14	NS	2.04	1.57	NS	2.22	1.94	NS
Early flowering	2.35	1.93	NS	2.14	1.86	NS	2.14	2.06	NS
Thick stem	2.80	2.50	NS	2.43	2.14	NS	2.70	2.35	NS
Leaf strength	2.25	2.50	NS	2.57	2.14	NS	2.35	2.47	NS
Large number of leaves	2.15	2.36	NS	2.29	2.57	NS	2.27	2.32	NS
Large number of sprouts	2.60	2.43	NS	2.50	2.86	NS	2.57	2.59	NS
Early maturity	2.55	2.29	NS	2.50	2.29	NS	2.41	2.44	NS
Sequential harvesting	2.95	3.00	NS	2.75	2.86	NS	2.97	2.79	0.013
High yield	3.00	3.00	NS	3.00	3.00	NS	3.00	3.00	NS
Tuber size	2.55	2.71	NS	2.75	2.43	NS	2.59	2.68	NS
Tuber number	2.40	2.43	NS	2.18	2.57	NS	2.43	2.26	NS
Utilization									
Suitability for boiling	3.00	2.93	NS	3.00	3.00	NS	2.97	3.00	NS
Suitability for stew	2.95	2.79	NS	3.00	3.00	NS	2.86	3.00	0.009
Market demand	2.75	2.29	0.037	2.82	2.86	NS	2.57	2.82	NS

† P value associated with X^2 test using Kruskal's rank test. Ratings are on a scale of 1 to 3, where 1 is low importance and 3 is very important.

Table 5-5: Percent of farmers rating traits as "very important"

Traits	Percent of farmers rating traits as "very important"*					
	Laigaint			Yilmana		
	Male	Female	Both	Male	Female	Both
Biotic and abiotic tolerance						
Drought tolerance	100	100	100	78.6	100	89.3
Low soil fertility adaptation	90.0	50.0	70.0	46.4	57.1	51.8
Tolerance to bird damage	50.0	42.9	46.4	10.7	28.6	19.6
Late blight resistance	90.0	100	95.0	96.4	100	98.2
Tolerance to tuber spoilage	75.0	64.3	69.6	64.3	85.7	75.0
Tolerance to wind and hail damage	70.0	85.7	77.8	64.3	85.7	48.2
Agronomic traits						
Long root system	50.0	42.9	46.4	10.7	0.0	5.3
Large plant height	15.0	14.3	14.6	0.0	0.0	0.0
High yield	100	100	100	100	100	100
Large leaves	40.0	28.6	34.3	17.9	0.0	8.9
Early flowering	50.0	35.7	42.8	32.1	14.3	23.2
Thick stem	80.0	57.1	68.6	50.0	42.9	46.4
Leaf strength	35.0	64.3	49.6	60.7	28.6	44.6
Large number of leaves	35.0	42.9	38.9	39.3	71.4	55.4
Large number of sprouts	65.0	42.9	53.9	53.6	85.7	69.6
Early maturity	55.0	57.1	56.1	60.7	57.1	58.9
Tuber size	60.0	71.4	65.7	75.0	42.8	58.9
Tuber number	40.0	42.9	41.4	21.4	57.1	39.3
Long shelf life	95.0	100	97.5	92.9	100	96.4
Suitable for sequential harvesting	95.0	100	97.5	75.0	85.7	80.4
Utilization						
Suitability for boiling	100	92.9	96.4	100	100	100
Suitability for stew	95.0	78.6	86.8	100	100	100
Market demand	75.0	35.7	55.3	82.1	85.7	83.9
Sample size	20	14		28	7	

*Compiled from the farmers' ratings on a scale of 1 to 3 where 1 is less important and 3 is very important.

Table 5-6: Variety characteristics perceived by farmers at flowering, during harvest, and after 3 months of storage

Variety	Positive traits	Negative traits
Enat Beguaro	High number of stems and high tuber number per plant, suitable for multiple harvests, tasty tubers, easily peeled after cooking	Susceptible to late blight, weak stems and leaves, tubers take long time to cook, poor storage quality
Abadamu	Very large leaf size (good soil cover), market desired tuber size, shallow eye depth, good storage quality	Susceptible to late blight, poor taste after boiling, weak stems
Siquare	Good canopy cover because of high number of leaves, early maturing, good for stew, intermediate storage quality, good market demand in nearby towns	Smooth tubers, the tubers are not as good as Abalo for boiling (Laigaint), apical dominance in sprout formation (low number of stems)
Feleke	Tall plant height	Small tubers, poor storage quality, very late maturing, susceptible to late blight
Bulle Local	Large leaf size, thick stems	Susceptible to late blight, purple tuber color is not attractive, weak and delicate leaves, very poor storage quality
Nech Abeba	Tall plant height, attractive round white tubers, high average tuber weight, thick stems	Susceptible to late blight, very poor storage quality
Key Shull	Very early maturing, firm after cooking	Very short plant, highly susceptible to late blight, not tolerant of wind, heavy rainfall, or low temp; very poor storage quality
Rejim China	Good height, good tolerance to lodging from strong winds, high total tuber yield	Late maturing, tubers not tasty, poor storage quality
Abalo	Thick stems, good adaptation to low soil fertility, moderate tolerance to drought after emergence, moderate tolerance to bird damage, suitable for multiple harvests, very good storage quality, suitable for boiling potato and stew	Susceptible to late blight, late maturing, the tubers are not attractive in large markets
Gera	Large plants, relatively tolerant to late blight, intermediate storage quality	Weak stems, susceptible to early blight, poor taste when boiled, deep eyes, medium storability
Jalene	Early flowering and maturity, high yield, good for boiling	Weak stems, tubers disintegrate when cooked, poor storage quality
Belete	Large leaves, strong stems, good tolerance to strong winds, high yield, good tuber size, early bulking, early maturing, late blight resistant, good stew quality	Quality after long storage is not as good as widely grown varieties, occasional unhealthy feeling in the throat after eating and 'stony' if cooled after boiling

Table 5-7: Farmers' ratings of four widely grown varieties based on several important traits

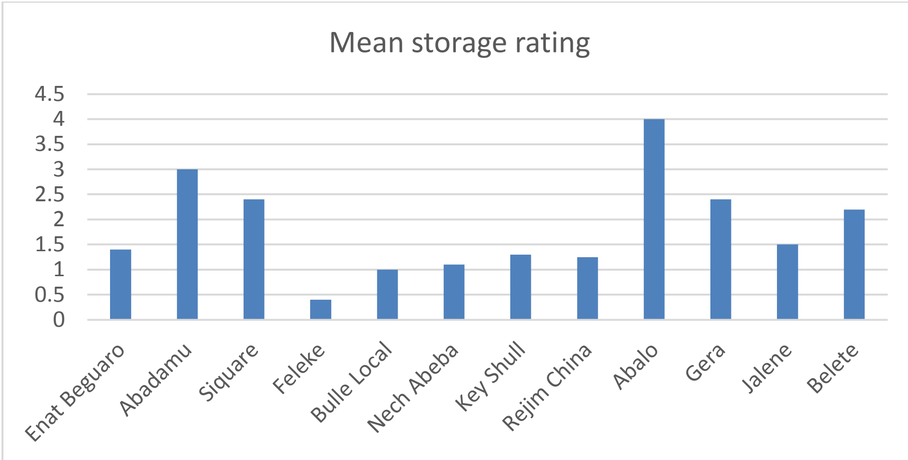
Traits	Abalo	Siquare	Belete	Jalene	Prob>X^{2}✞
Biotic and abiotic tolerance					
Drought tolerance*	3.00	1.00	2.71	1.00	0.0001
Low soil fertility adaptation**	2.77	1.00	1.29	1.00	0.0001
Bird damage tolerance	2.92	1.00	1.14	1.00	0.0001
Late blight resistance*	1.80	2.00	3.00	1.67	0.0001
Winds and hail damage tolerance*	2.54	1.27	3.00	1.33	0.0001
Tuber spoilage tolerance*	2.85	2.36	2.57	1.00	0.0002
Agronomic traits					
Long shelf life*	3.00	2.19	2.00	1.17	0.0001
Long root and stolon system	2.62	1.09	1.00	1.50	0.0001
Large leaves	1.92	1.27	2.86	2.33	0.0001
Early Flowering	1.00	3.00	2.86	3.00	0.0001
Thick stem	2.00	1.91	2.71	2.67	0.0008
Leaf strength	2.31	1.00	2.86	1.50	0.0001
Large number of leaves	1.77	3.00	2.71	2.50	0.0001
Large number of sprouts	2.00	2.73	2.29	2.67	0.0310
Early maturity	1.00	3.00	3.00	2.83	0.0001
Sequential harvesting*	3.00	1.00	1.00	1.00	0.0001
High yield*	2.07	2.23	3.00	2.83	0.0001
Tuber size	1.85	2.91	3.00	2.83	0.0001
Tuber number	2.54	2.49	3.00	2.83	NS
Utilization					
Taste as boiled potato*	3.00	2.18	2.14	2.17	0.0001
Suitability as table potato*	3.00	1.18	1.43	1.83	0.0001
Stew quality*	3.00	2.45	2.86	2.00	0.0016
Market demand***	1.92	2.73	3.00	2.67	0.0002

✞Kruskal-Wallis rank test; Rating on a scale of 1 to 3 where 1 is less important and 3 is very important. *Very important traits for both districts, ** very important trait for Laigaint, *** very important trait for Yilmana.

5.2.8 Agronomic performance of local potato varieties compared to improved varieties in different environments

The ANOVA and AMMI analyses indicated that there are significant differences among varieties, between environments and in variety by environment interactions in terms of average tuber weight, marketable and total tuber yields. Most of the tested varieties gave higher marketable and total tuber yield at Laigaint in the Meher season versus both districts in the Belmehr cropping season. The lowest yield was recorded at Yilmana during the Meher season due to repeated hail damage. Early bulking varieties such as ‘Belete’ and ‘Gera’ (new), and ’Nech Abeba’ and ‘Abadamu’ (local) yielded well (marketable and total yield) in both Meher and Belmehr seasons. Unsurprisingly, late maturing local varieties such as ‘Abalo’ and ‘Rejim China’ had higher marketable yield in the Belmehr season compared to the Meher season (Table 5-8). ‘Bulle Local’ and ‘Feleke’ had high total tuber yield in both seasons at Laigaint and in the Belmehr season at Yilmana, but their marketable yields were low.

The performance of varieties in relation to late blight, lodging due to wind and damage due to hail is shown in Fig 5-4. Two new varieties, ‘Belete’ and ‘Gera’, and one local variety, ‘Siquare’, showed resistance to late blight while the other varieties were variably affected. In Laigaint during the Meher season, local varieties ‘Feleke’, ‘Nech Abeba’, ‘Rejim China’ and ‘Bulle Local’ and one new variety (‘Belete’) showed some tolerance to lodging from wind while ‘Belete’ and ‘Abalo’ showed some tolerance to hail damage at Yilmana in the Meher season. All of the varieties that showed tolerance to wind and hail damage have thick stems compared to susceptible varieties.



Data was compiled from farmer ratings on a scale of 0 to 4; 0 denotes poor storability while 4 is long storability in farmers' in-house storage

Figure 5-3: Farmers' rating of varieties in terms of quality three months after storage.

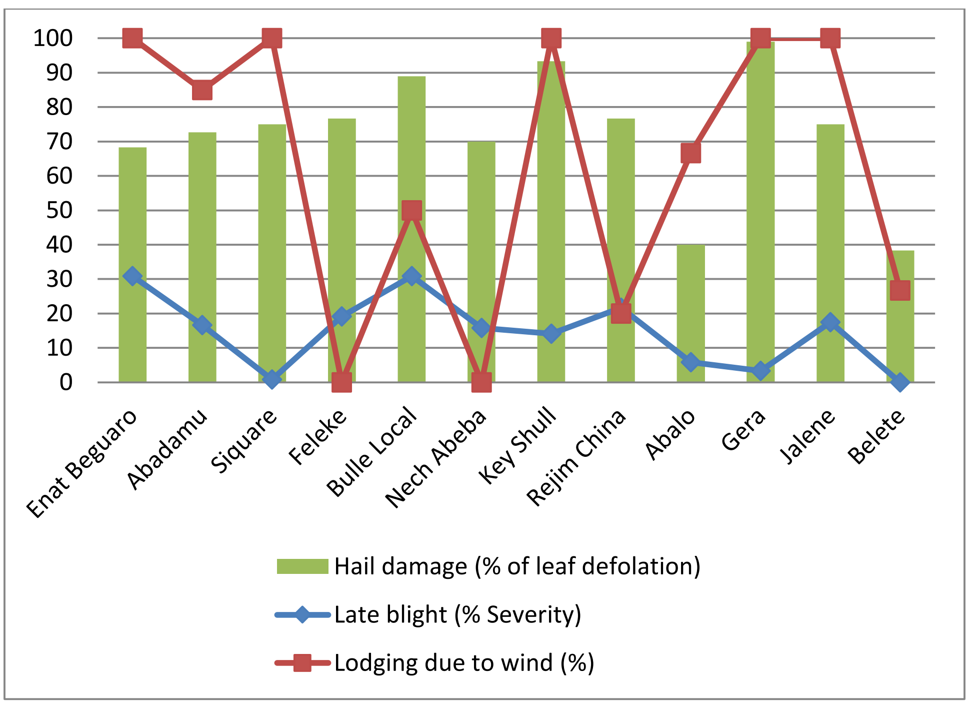


Figure 5-4: Varietal differences in defoliation caused by hail (Meher season), frequency of lodging due to strong winds (Meher season) and severity of late blight (Belmehr season).

Table 5-8: Marketable (MTY) and total tuber yield (TTY) in tons/ha of the varieties tested during 2014 in two different seasons and two districts

Variety	Laigaint				Yilmana			
	Belmehr		Meher		Belmehr		Meher	
	MTY*	TTY	MTY	TTY	MTY	TTY	MTY	TTY
Enat Beguaro	9.1 bc	14.8 abc	5.0 f	11.7 e	2.6 e	12.4 c	0.9 d	1.3 d
Abadamu	14.0 ab	15.8 ab	20.1 a	24.0 a	12.5 abc	15.9 abc	5.3 b	6.8 b
Siquare	12.8 abc	15.1 abc	15.8 abc	21.2 abc	9.9 bcd	14.1 bc	5.5 b	7.3 b
Feleke	9.1 bc	15.2 abc	9.5 def	15.5 de	8.0 cde	21.5 a	2.3 cd	3.2 cd
Bulle Local	8.4 c	14.4 abc	13.8 bcd	21.7 abc	7.5 cde	15.6 abc	3.2 c	6.6 b
Nech Abeba	13.1 abc	16.0 ab	20.5 a	24.8 a	14.9 ab	22.5 a	4.1 bc	5.3 bc
Key Shull	7.7 c	10.1 c	12.4 cde	16.3 cde	5.7 de	13.4 c	2.4 cd	3.0 cd
Rejim China	13.5 ab	18.8 a	12.6 cde	19.8 abcd	12.1 abc	21.0 abc	3.8 bc	5.0 bc
Abalo	11.7 abc	16.5 ab	8.5 ef	15.4 de	14.4 ab	21.5 a	5.1 b	7.0 b
Gera	10.7 abc	13.8 bc	18.1 ab	20.0 abcd	11.2 abc	15.5 abc	4.1 bc	5.3 bc
Jalene	12.7 abc	14.7 abc	15.8 abc	18.5 bcd	14.2 ab	21.7 a	5.2 b	6.3 b
Belete	15.6 a	16.8 ab	17.2 abc	22.1 ab	15.9 a	19.0 abc	9.6 a	12.2 a
Mean	11.56	15.33	14.12	19.24	10.75	17.85	4.3	5.79

*varieties with similar letters are not significantly different at P<0.05.

5.4 Discussion

Both the farmers' ratings for factors that limit production and the Additive Main effect and Multiplication Interaction model (AMMI) analysis on tuber yield showed that there are clear differences between the Behlmehr and Meher seasons and the two agroecological zones studied in relation to potato variety performance. Although the degree of importance differs between locations, erratic rainfall patterns in the Belmehr season and late blight in Meher season are important limiting factors. Bekele and Eshetu (2008) stressed the importance of late blight in the Meher season that forces farmers to plant in the dry season (Belg or Belmehr) even if the farmers are aware that yield will be reduced. Moreover, as we observed during the Meher season, heavy rainfall and hail damage in Yilmana and high and desiccating wind in Laigaint are limiting factors for most late maturing varieties.

All of these production challenges relate to farmers' existing practices and the varieties under possession. Other production problems not cited by farmers may be relevant when new varieties are introduced. For instance, as indicated in Tables 5-4 and 5-5, traits such as long storability, sequential harvesting and culinary qualities are ranked highly by farmers in both locations and gender groups. However, farmers did not mention these traits as a production challenge because they already have varieties that provide these qualities.

Moreover, the soil sample analysis shows that soils in both locations were potassium depleted. Potassium depletion might be one of the factors for low yields at both sites. This deficiency is known to reduce crop yield (Umar and Moinuddin, 2001) and increase susceptibility to different stresses (Brady and Weil, 2002). Farmer rating of variety traits also shows that the ability to grow on low fertility soil is important. Unavailability of potassium fertilizer in the country coupled with inadequate chemical fertilizer application may limit potato production in these agroecological zones. It is worth noting that the Adet Agricultural Research Center (Abebe et al. 2008) does not currently recommend potassium fertilizer for potatoes. The low emphasis placed on potassium in Ethiopia today is likely the result of a 47-year old study reporting that Ethiopian soils are rich in potassium (Murphy, 1968).

Variability in local conditions and between seasons contributes to the diversity of varieties that farmers choose to grow in Yilmana and Laigaint. 'Abalo' and 'Siquare' are local varieties that are grown in the Belmehr season in both districts while new varieties such as 'Belete' and 'Jalene' are grown mainly in the Meher season. Our study found that late maturing varieties (all local) are best suited to Belmehr season production while early bulking ones (two local and two improved varieties) are best suited to Meher season production. This is not surprising as late maturing varieties need a long growing season. Also, the short growing season coupled with late blight severity and desiccating wind contributed to low yield of late maturing varieties in Meher season production. Some of the early bulking varieties such as 'Belete', 'Abadamu' and 'Nech Abeba' performed well during Belmehr season, presumably due to the favorable rainfall distribution for potato growth as shown in Fig 5-1.

Information on farmers' selection criteria is one of the important outputs of PVS (Wakijira et al. 2008). Our study showed that the farmers consider up to 23 crop traits important for variety selection in the two districts, representing two major agroecological zones. Other studies have reported that resource poor farmers give more attention to yield stability, quality, and secondary uses (Thiele et al. 1997; Almekinders and Elings, 2001). Nonetheless, the relative importance of some of these characters differed between districts and gender groups. Apart from yield and late blight resistance, long shelf life, suitability for boiling (good taste), stew quality (remains firm when cooked and better absorption of fat/oil from the stew) and drought tolerance are important selection criteria for both districts and gender groups; these factors undoubtedly influence the acceptance of new varieties. While farmers consume potatoes both boiled (cooked potato used before cooling down, nothing added) and in stew (known as “Wot”), urban dwellers primarily consume potato in a stew mixed with vegetables (known as “Alicha”). For stew preparation, potato is cut into pieces before cooking; these pieces are then mixed with vegetables and spices and cooked with oil. For boiled potato, the tuber is cooked whole without any spices added.

A previous study showed that early maturity, tuber size and some morphological characters are important variety selection criteria for farmers in Bolivia (Thiele et al. 1997). Early maturity for Meher season production is currently a high priority trait for Ethiopian potato variety developers. However, our study shows that approximately 40% of farmers did not consider early maturity as a “very important” trait in the Belmehr season as they can adjust the varieties they grow each year depending on when the rain starts. In some years where the rainfall starts early in the Belmehr season, late maturing varieties like ‘Abalo’ perform well, otherwise early maturing varieties like ‘Siquare’ are planted to harness the late season rain. By doing this, farmers position themselves to adapt to weather variability and maximize their food security. Thick stems are related to a variety’s ability to limit lodging (at Laigaint) and tolerate heavy precipitation including hail (at Yilmana). Similarly, Thiele et al. (1997) indicated that thick stems, plant height, abundant foliage, large tuber size and market related characters are important selection criteria for farmers. We found that tolerance to bird damage was important to farmers in Laigaint as birds are a common problem during planting and after vines have matured (tubers are left unharvested for up to 6 months), and hence varieties with long stolons are preferred.

In both districts farmers prefer varieties that store well for two reasons. First, farmers depend on potato as their primary food source for more than seven months. These potatoes are typically stored in their homes and kept in darkness. Second, farmers generally use seed from one Belmehr crop for the next Belmehr season; hence tubers need to be stored in situ (in-field) and/or in storage structures for at least seven months. These practices require long shelf life as a varietal trait, and this will influence acceptance of varieties in these two locations.

The importance of quality traits such as storability, taste and other uses are generally overlooked in current variety development efforts in Ethiopia. Tripp et al. (1997) described how traits such as cooking quality, taste, market acceptability and storability are not considered in variety release by public institutions. One of the conclusions of our study is that the variety requirements of resource poor farmers are more diverse than breeders' perceptions, a view shared by several other investigators (Mulatu and Zelleke, 2002; Morris and Bellon, 2004; Vom Brocke et al. 2010).

Our study further shows the existence of variety selection criteria that vary by agroecological and gender groups. Differences in farmer selection concerns between the two districts are a function of agroecological differences and access to market outlets. Since Laigaint represents a sub-moist (dry) agroecology and is food insecure, the most important variety traits are drought tolerance and suitability to sequential harvesting (including related traits such as long stolons). Farmers' preference for varieties suitable for soil with poor fertility is also related to drought because under conditions of low soil moisture if is more difficult for plant roots to access nutrients in the soil. Farmers in Yilmana are economically better off than their counterparts in Laigaint, and they are thus more concerned with market traits including stew quality. Differences were also clearly observed between gender groups in Laigaint, as women were more concerned with the trait of long stolons (related to sequential harvesting which provides food over a longer period of time) while the men were more concerned with low soil fertility and market traits.

The large number of variety traits important to farmers of both genders in both agroecological zones suggests a need for a diverse set of varieties because it is impossible to find all of these traits in a single variety. Farmers grow multiple varieties to obtain a range of variety traits at the same time; more than 77% and 22% of the farmers at Yilmana and Laigaint, respectively, grew two or more varieties in the same season (our study). Mulatu and Zelleke (2002) found similar results in their study on highland maize in Ethiopia. The potato varieties from southern Ethiopia (SNNP and Oromia) do not fit the farming system of the two northwestern agroecological zones, mainly because of short storability and susceptibility to late blight. Two local varieties (‘Abalo’ and ‘Siquare’) and one improved variety (‘Belete’) have more preferred traits than the other varieties evaluated. ‘Abalo’, despite its drawbacks such as late blight susceptibility, late maturity for Meher season production, and poor tubers for market purpose, fits well for Belmehr season production due to its long shelf life, suitability for sequential harvesting, excellent taste after boiling and good stew quality. However, the production of ‘Abalo’ in the Yilmana district has dramatically decreased within the last three years because of a shift in rainfall from March to May and an increase in late blight disease pressure. ‘Siquare’, another variety dominant in northwest Ethiopia is now replacing ‘Abalo’ in Yilmana because of its relatively good resistance to late blight, good market acceptance and suitability for late planting. This variety, however, is not accepted as a boiling potato in Laigaint, not useful for French fry making in the cities, and not tolerant of strong wind because of its thin stem and delicate leaves. ‘Belete’ is preferred by farmers for its high yield, good late blight resistance and better stew quality, and has better tolerance to some major abiotic stresses such as desiccating wind and severe precipitation; this is likely due to its strong stems and thick leaves. Our agronomic data also revealed that ‘Belete’ has very good yield stability across districts and seasons. However, this variety is not valued by farmers because it does not store well.

5.5 Conclusions

Potato is one of the few crops in Ethiopia that matures during the months of July and August and thus has an important role in alleviating hunger. Belmehr season production is what most farmers employ to fill their food gaps. Existing new varieties do not provide an effective solution to farmers for production during Belmehr because of poor storability and their generally poor performance in the Belmehr season. Expanding Ethiopian variety development efforts to include Belmehr season production is of paramount importance. Apart from yield and late blight resistance, developing varieties suitable for long storage and sequential harvesting together with better boiling and stew quality needs to be given high priority. The study further shows that several local varieties, such as ‘Abadamu’, ‘Nech Abeba’, ‘Rejim China’ and others yielded as well or better than new varieties in both seasons using disease tested seed. This finding negates the belief that Ethiopian local varieties are low yielding. Importantly, farmers’ local varieties can serve as valuable resources for future variety improvement, as they have the necessary qualities and are well adapted to the farming systems of the two agroecological zones. Spraying local varieties for late blight control at least once, promoting use of non-chemical fertilizers such as compost and animal manure, and applying chemical fertilizers (especially potassium) may increase potato productivity in the Belmehr season. New varieties are already playing an important role in complementing existing local varieties during the Meher season production and can be used for immediate consumption as well as for markets. About 47% and 35% of the participating farmers at Yilmana and Laigaint, respectively, currently grow new varieties, primarily ‘Belete’ (current study). Introducing additional varieties with good shelf life may also help farmers who grow potato during the Meher season.

This study together with our previously published work (Kolech et al. 2015) helps us understand farmers' variety needs and farmers' production practices as they relate to variety selection. Moreover, these studies help us catalog attributes of local varieties for future use and conservation. Therefore, these studies are the first step for fulfilment of our general objective of developing potato varieties that are well suited to the needs of growers and consumers and that also increase potato productivity. This study further shows that the PVS approach is helpful in understanding the relative importance of farmers concerns in variety selection.

This case study is based on two major agroecological zones that nevertheless employ the same cropping system in northwest Ethiopia (Amhara region). The results of this study can be applied to similar agroecologies and cropping systems in northwest Ethiopia. Since Southern Ethiopia has a different cropping system and grows different varieties than the northwest, a similar study needs to be conducted in that region. Similar studies could also be conducted in central and Eastern highland areas to understand farmers' variety needs and assess the local potato genetic resources located there.

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CHAPTER 6: **CONCLUSIONS AND RECOMMENDATIONS**

This dissertation has two major goals: i) to document the distribution and importance of Ethiopian local potato varieties; and, ii) to understand what traits farmers need in new varieties. To achieve these goals, four independent studies were conducted, as follows: 1. Potato variety diversity, determinants and implications for breeding strategy in Ethiopia (Chapter 2); 2. Genetic diversity and relationships among Ethiopian varieties compared to major world potato clones (Chapter 3); 3. Genotypic variation in potato growth and yield response to water stress during cool and warm seasons production in northwest Ethiopia (Chapter 4); and 4. Identification of farmer priorities through participatory variety selection (Chapter 5).

Studies presented in Chapter 2 include semi-structured questionnaires, group discussions, and field and storage observations to document major varieties, their distribution, and merits. Important varieties, along with their characteristics and areas of adaptation, were documented. The distribution of these varieties differed across agro-ecologies. The study also cataloged the number of varieties grown per household; the majority of farmers (70-90 %) reported planting two or more varieties each growing season.

Questionnaires were devised to assess what determined variety acceptance in six diverse agro-ecologies as well as the reasons why many new varieties have not been adopted as expected. Apart from yield and late blight resistance (the primary selection criteria of breeders in Ethiopia), drought tolerance, storage quality, taste and suitability for consumption when boiled and/or used in stew were traits that farmers in all of the studied agroecologies required when selecting a variety. Other traits are also important, but their significance was limited to specific agroecological zones and cropping systems, and varied with extent of market access. For districts with better access to markets, such as Shashemene and Yilmana, farmers prefer to grow varieties that meet market demands, including better stew quality. Adaptation to low soil fertility and suitability for multiple harvests are important traits for sub-moist agro-ecological zones of the Amhara region. Varieties with long dormancy are necessary for northwest Ethiopia and Guraghe districts while varieties with short dormancy are important for southern Ethiopia, including the Shashemene district.

An assessment of Ethiopian potato genetic resources using molecular and morphological markers is described in Chapter 3. 8303 SNP markers were used to characterize 44 local potato varieties collected from two major potato production areas (Northwest and South Ethiopia). Only 15 of the 44 local varieties are truly unique, the rest were found to be duplicates, known by different names. The 15 unique Ethiopian clones harbor considerable genetic variation, comparable to that found in CIP, American and European clones. Some Ethiopian clones appear to have descended from European germplams; other Ethiopian clones are most closely related to germplasm developed by CIP. This study negates the belief that Ethiopian local potato varieties have a narrow genetic base. Harmonizing names for the 15 unique genotypes is the first step in registering these varieties for future use.

As discussed in Chapter 4, seed of local varieties, together with selected new varieties and clones from outside sources, were tested under water stressed and irrigated conditions in two potato growing seasons, Mesino (cool growing season) and Belg (warmer growing season). Seed of the local varieties was multiplied *in vitro* and in screen houses using pathogen-tested tubers to avoid confounding effects from diseases. Varietal response to drought differed among seasons suggesting a difference in adaptation of varieties between seasons. The drought in both seasons was characterized as late onset, hence early bulking varieties with higher harvest index gave higher marketable tuber yield and a lower stress susceptibility index. 'Granola' was found to be the best variety in the Belg season due to its high marketable tuber yield, low stress susceptibility index and low tuber deformation. In the Mesino season, 'Gera' and 'CIP-395109.34' were found to be promising. These varieties may make good parents in a future breeding program. The results indicate potential for improving dry season potato production in Ethiopia by utilizing both selected local and new varieties. Moreover, the results show that high harvest index, increased root length under stress, and relatively few deformed and small tubers are traits associated with high marketable yield potential and stability under both irrigated and drought stress conditions.

As described in Chapter 5, a participatory variety selection (PVS) approach was used to investigate yield and yield stability of local and new varieties grown using farmers' cultural practices. PVS was also used to investigate farmers variety needs across agro-ecological zones and gender groups. Farmers' research groups were established and asked to evaluate varieties at different growth stages as well as in storage. This activity assessed nine selected local varieties along with three new varieties in farmers' fields in two major growing seasons and two major ecological districts. To avoid confounding effects due to diseases, each local variety was raised from disease tested seed. The storage quality of these varieties were also assessed under farmers' storage practices to determine whether they are compatible with farmers' variety needs. The results showed that several local varieties, such as 'Abadamu', 'Nech Abeba', 'Rejim China' and others yielded as well or better than new varieties in both seasons when using disease tested seed. This finding negates the belief that Ethiopian local varieties are low yielding. There is a clear difference in performance of varieties between seasons; late maturing varieties are well adapted to the Belmehr season while early maturing ones with thick stems and leaves that resist high wind stress and extreme rainfall events are well adapted to the Meher season. One striking difference in the needs of southern and northwestern varieties relates to tuber dormancy: varieties from the South have short dormancy (which allows two crops per year), but these varieties are not suitable for the long-term storage needed by farmers of northwest Ethiopia.

PVS is an effective approach for identifying factors important for potato variety adoption, including factors that may not be addressed in conventional potato breeding programs. Using PVS we uncovered several reasons why farmers don't want to grow potato in the main rainy season, even though moisture is not adequate for adequate growth of the crop in the dry season. One reason is related to filling the food gap during the "hungry months', that is July and August, and the second reason is related to late blight damage on their local varieties during main rainy season production. During the Belmehr season, erratic rainfall results in low yield and lower average tuber weight. By contrast, in the Meher season, late blight, desiccating wind and severe precipitation, including hail, limit production. Farmers cited 23 important traits for variety selection, with varying degrees of importance for each trait across agroecological zones and between gender groups. Our study further showed that although both gender groups have similar concerns in the majority of variety selection traits, in Laigaint (a dry environment) women were more concerned with the trait of long stolons (related to sequential harvesting, which provides food over a longer period of time), while the men were more concerned with marketability. Recognizing such differences could lead to better adoption of new varieties.

Based on the research described, the following recommendations can be made for potato variety improvement and conservation in Ethiopia.

Register Ethiopian local varieties, and prepare an Ethiopian potato catalog

The Ethiopian Ministry for Agriculture publishes a variety registration booklet for officially released new varieties on an annual basis. However, since the booklet does not provide detailed descriptions and photographs of new varieties, it is easy for a variety to lose its identity and gain additional names. Preparing an Ethiopian potato catalogue that includes the most widely grown local varieties will help ensure that everyone identifies a clone with the same name. This, in turn, will help reduce unnecessary duplication of effort in future research and conservation projects.

Utilize available local and new varieties for future breeding

Ethiopia has unique and diverse agro-ecologies, different cropping systems and specific end uses that justify the need for many types of potato varieties. Local and selected new varieties provide a useful starting point for the development of improved varieties, as they represent the collective, if not technologically sophisticated, efforts of countless farmers to identify clones that meet current needs. Of course a breeding program requires a long-term financial commitment to ensure that adequate human resources, equipment, and facilities can be harnessed for the development of new varieties. It is possible to establish such a program at the national level, where crossing is done at a single location, and subsequent evaluation is conducted in research centers around the nation. The support of the International Potato Center and other institutions would be of tremendous help in establishing an Ethiopian breeding program.

Multiply disease tested starter seed of local varieties

Tissue culture facilities in the country currently multiply disease tested seed of new- but not local – varieties. The present study showed that most local varieties have degenerated due to accumulation of virus diseases such as PVM, PVS, PVX, PVY, PLRV and a bacterial disease, bacterial wilt. Distribution of diseased tested mini-tubers of major varieties such as 'Siquare', 'Abalo', 'Samune' in Northwest Ethiopia, and 'Agazer', 'Nech Abeba' and 'Bulle' in parts of Oromia (Shashemene, East Arsi and Bale) for starter seed may help significantly improve the performance of these varieties. Disease tested plantlets of most of the widely grown local varieties (except 'Samune') have been established at the ARARI Tissue Culture laboratory in Bahir Dar, Ethiopia, and it is possible to multiply these varieties on a larger scale.

Incorporate additional quality and stress tolerance traits during variety development

Our study showed that a variety will not necessarily be adopted even if it has high yield and late blight resistance (which have been the major goals of variety development in Ethiopia), as several other factors also contribute to variety adoption. Most of the new varieties that have not been adopted so far either have poor taste after boiling, undesirable stew quality, and/or poor storability. Several authors have stressed the importance of quality traits - such as storability, taste for both boiling and stew, and market demand for variety adoption. Ideally, variety development should include assessment of all quality traits that are important determinants of variety adoption.

Address the variation in agro-ecology, cropping systems and market access during variety development

Key traits differ among agro-ecologies, cropping systems and market outlets. This needs to be taken into account during variety development. For instance, in Gumer & Geta, late blight resistance and long storage life are the key traits that enable farmers to grow potato in the Meher season and allow year round consumption of potato. Resistance to late blight, suitability for boiling and stew, and long storability are the major drivers for variety adoption in Amhara areas with moist and sub-humid agro-ecologies. In Amhara areas with sub-moist agro-ecology, long storability, drought tolerance and suitability to boiling potato are the major drivers for adoption. Market quality (desirable tuber size, color, shape) are key for variety adoption in the Yilmana district. Marketability, suitability for stew, and early maturity are important traits for adoption of new varieties in the Shashemene area. In contrast to other districts, farmers in Shashemene prefer varieties with short dormancy to enable them to grow two crops a year.

Address different potato growing seasons for improvement of the crop

Potato is grown in four different seasons in Ethiopia: Belmehr, Meher, Belg and Mesino. The Ethiopian potato variety improvement program has focused on Meher (rainy) season production even though most farmers grow potato in the other three (dry) seasons. Farmers want to grow potatoes in the dry season even though they realize the challenges and low yields in part because they need something to eat in the critical food gap "hungry months" of July and August and in part to avoid the substantial late blight damage that potatoes suffer in the main rainy season. Promoting the use of weather advisory services would be helpful, so farmers can make more informed decisions of when to plant in the dry season. Developing potato varieties with contrasting maturity traits, so farmers have options about what variety to plant, depending on when rainfall starts, would also be useful, as would promoting the use of water conservation practices and other cultural practices to maximize yield during dry season production.

Design effective variety dissemination approaches

New variety adoption in the Gumer & Geta districts provides a good model of a successful dissemination strategy. Here, in addition to providing an adequate supply of clean seed, growers were provided with variety specific recommendations for fertilizer, seed storage structures, and support that continued for five years. Strong coordination among developmental partners helped the adoption process.

APPENDIX

Appendix A1: Released potato varieties in Ethiopia (from 1987- 2012)

No	Variety given name	First name	Year of release	Responsible center*
1	Milki	CIP-394640.539	2012	Sinana ARC
2	Moti	KP-90147.41	2012	Sinana ARC
3	Bubu	CIP-384321.3	2011	Haramaya University
4	Red Scarlet	Red Scarlet	2010	HZPC-SolaGrow
5	Caesar	Caesar	2009	HZPC-SolaGrow
6	Mondial	Mondial	2009	HZPC-SolaGrow
7	Belete	CIP-393371.58	2009	Holetta ARC
8	Dancha	CIP-392618.511	2009	Sinana ARC
9	Kulumsa	KP-90143.5	2007	Kulumsa ARC
10	Hundee	KP_90147.8	2006	Sinana ARC
11	Araarsaa	KP-90138.12	2006	Sinana ARC
12	Gudenie	CIP-386423.13	2006	Holetta ARC
13	Gabbisa	CIP-387096.11	2005	Haramaya University
14	Shonkolla	KP-90134.5	2005	Awassa ARC
15	Bulle	CIP-387224.25	2005	Awassa ARC
16	Challa	CIP-387412.2	2005	Haramaya University
17	Mara Charre	CIP-389701.3	2005	Awassa ARC
18	Gera	KP-90134.2	2003	Debre Birhan ARC**
19	Gorebella	CIP-382173.12	2002	Debre Birhan ARC
20	Guasa	CIP-384321.9	2002	Adet ARC
21	Jalenie	CIP-37792.5	2002	Holetta ARC
22	Degemegn	CIP-384321.19	2002	Holetta ARC
23	Zemen	AL-105	2001	Haramaya University
24	Bedasa	AL-114	2001	Haramaya University
25	Zengena	CIP-380479.6	2001	Adet ARC
26	Chiro	AL-111	1998	Haramaya University
27	Wechecha	Krolisa	1997	Holetta ARC
28	Tolcha	UK-80.3	1993	Holetta ARC
29	Menagesha	CIP-374080.5	1993	Holetta ARC
30	Awash	CIP-378501.3	1991	Holetta ARC
31	Alemaya 624	AL-624	1987	Haramaya University

* ARC= Agricultural Research Center

** Debre Birhan, the then Sheno Agricultural research center

Source: MOA. 2013. Crop Variety registry book.

Appendix A2: Incidence of potato virus diseases in different potato growing areas

Variety	Collection site	Adaptation Zone	# of samples	PVA	PVM	PVS	PVX	PVY	PLRV
Kuchibiye	Rob Gebeya	East Gojjam	4	0	0	50	75	0	0
Siquare	Rob Gebeya	East Gojjam	4	0	0	75	100	0	0
Abadamu	Rob Gebeya	East Gojjam	4	0	0	75	100	0	0
Abateneh	Adet	West Gojjam	4	0	0	75	100	0	0
Ayito	Arb Gebeya	West Gojjam	4	0	0	0	0	0	0
Agere	Rob Gebeya	East Gojjam	4	0	0	25	75	0	0
Volvo	Kofele	East Arsi	4	0	0	50	75	0	0
Gojjam (Sin 22)	Bekoji	East Arsi	4	0	0	0	75	25	0
Durame	Damote Gale	Wolayita	4	0	0	0	25	0	0
Akime	Genko/Adera	Gamo	4	0	0	0	25	0	0
Gedigala	Adera Got	Gamo	4	0	0	25	25	25	0
Holland	Bekoji	East Arsi	2	0	0	0	50	0	0
Rejim China	Kofele	East Arsi	4	0	0	0	75	0	0
Siquare (SIN 17)	Woyra	Sidama	4	0	0	100	100	0	0
Durame Shull	Wonda	Sidama	4	0	0	0	25	0	0
Meze fazer	Azo Tala	Gamo	4	0	0	75	0	0	0
Siasay	Adet (Goshiye)	West Gojjam	4	0	0	0	0	0	0
Siquare	Arb Gebeya	West Gojjam	4	0	0	100	100	0	0
Nech Abeba	W.Wendo	Sidama	4	0	0	25	75	0	0
Bulle	Kofele	East Arsi	4	0	0	25	25	0	0
Feleke	Chencha	Gamo	4	0	0	0	50	0	0
Achire	Damote Gale	Wolayita	8	0	0	0	62.5	0	0
Key Shull	Shashemene	East Arsi	4	0	0	75	0	0	0
Asmera	Damote Gale	Wolayita	4	0	0	0	100	0	0
Nech Abeba	Shashemene	East Arsi	3	0	0	33.3	100	0	0
Siquare	Bekoji	East Arsi	4	0	0	100	100	0	0
Agazer	Shashemene	East Arsi	4	0	0	0	50	0	0

Variety	Collection site	Adaptation Zone	# of samples	PVA	PVM	PVS	PVX	PVY	PLRV
Samune	Arb Gebeya	West Gojjam	4	0	0	100	100	0	0
Key Abeba	Shasho	Sidama	4	0	0	50	25	0	0
Abateneh	Sekela	West Gojjam	17	0	66	94	94	18	10
Ayito	Arb Gebeya	West Gojjam	10	0	10	43	56	0	0
Abadamu	Arb Gebeya	West Gojjam	1	0	0	100	100	0	0
Abalo	Arb Gebeya	West Gojjam	2	0	0	100	100	0	0
Abadamu	Arb Gebeya	West Gojjam	12	0	97	99	90	10	0
Agere	Rob Gebeya	East Gojjam	5	0	60	10	75	0	0
Siquare	Arb Gebeya	West Gojjam	17	0	94	94	88	6	0
Enat Beguaro	Rob Gebeya	East Gojjam	17	0	80	80	90	10	10
Samune	Arb Gebeya	West Gojjam	7	0	14	70	42	0	0
Siquare	Arb Gebeya	West Gojjam	10	0	90	90	90	0	10
Abateneh	Arb Gebeya	West Gojjam	7	0	14	72	42	0	0