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Borlaug LEAP Paper

Understanding farmer needs and unlocking local genetic resources for potato improvement: a case study in Ethiopia

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ABSTRACT

Understanding farmers' needs and local genetic resources are crucial steps to improve and conserve the potato crop. A study was conducted to understand what potato traits Ethiopian farmers consider most important, and to characterize the diversity and distribution of local varieties. Growers from six districts were surveyed in 2012 and 2014. Based on the survey results, participatory variety selection (PVS) activities were conducted in two districts during two production seasons. Simultaneously, local varieties were collected from northwest and southern Ethiopia and characterized using molecular and morphological markers. Farmers identified 23 traits they considered important for variety selection, with the degree of importance for each trait varying across gender groups, agro-ecological zones, and growing seasons, as well as with extent of market access. The distribution of local varieties varied by agro-ecological zone, cropping system and proximity to markets. Our genetic fingerprinting and morphological characterization further revealed that, 34% of 44 local potato varieties collected are truly unique, the rest were duplicates, known by different names. These unique Ethiopian local varieties harbour considerable genetic variation, compared to the variation found in European and North American clones. Although local varieties may have lower yield than commercial varieties, they have other desirable attributes that make them well suited for alternative uses and different agro-ecologies.

Key words: Participatory variety selection, Gender, Local potato varieties, agro-ecological zones, growing seasons, genetic fingerprinting

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INTRODUCTION

Potato is considered by FAO (2009) as a food security crop that helps to meet the rising food demands in the tropical highlands of sub-Saharan Africa. Due to the potato's short cropping cycle and higher production per hectare per day when compared to other arable crops (FAO, 2009), potato provides hope for improving the lives of millions of poor farmers in the risk-prone highlands. In Ethiopia, potato is grown in a wide range of agro-ecological zones, during four different growing seasons and is considered a "hunger breaking crop" because it can be grown in dry areas under conditions where other crops fail. Indeed, potato is the only food crop grown to any large extent in the dry season where rainfall is erratic and unpredictable in the months of March through May (Kolech *et al*., 2015a).

According to Labarta (2012) and Scott *et al.* (2013), potato production expansion was more rapid in Africa than any other region in the world. Most of this expansion has been seen in East African countries including Ethiopia, Rwanda, Tanzania and Uganda. Emerging markets for processed products such as chips and French fries have also been gaining momentum in these countries (Tesfaye *et al*., 2010). However, at 7.8 t/ha (Schulte-Geldermann, 2013) potato production in this region is much lower than other regions of the world. These relatively low yields have been attributed to several factors including the use of low yielding varieties and poor quality seed, poor disease and pest management, inadequate soil fertility and water stress (Kolech *et al*., 2015a).

Most potato variety selection programs in sub-Saharan Africa (SSA) started in the 1970s with the goal of increasing potato productivity in the region. Prior to 1980 germplasm was introduced mainly from Europe (United Kingdom, Germany and the Netherlands) (Kidane Mariam, 1979; Lungaho *et al*., 2011). Up to1990 several national programs in SSA benefited from the introduction of late blight resistant materials from Mexico with the support of the Rockefeller foundation (CIP, 1972), as well as from European materials. Since the late 1970s, the International Potato Center (CIP) and its partners have worked together to breed and select improved clones, culminating in the release of many new varieties in SSA. Most of the crossing and early generation selections have been done by CIP while National Agricultural Research Institutes (NARIs) in SSA have done most of the late generation selection. About 65% of potato varieties released in SSA over the last decade were CIP originated clones. A total of 117 improved varieties were released in Ethiopia, Kenya, Uganda and Tanzania between 1990 and 2011 (Labarta, 2012). Ethiopia released 29 new varieties (of which 26 were CIP originated) during this time frame (MOA, 2014), while Rwanda, Tanzania, Uganda and Kenya released between 18 and 23 varieties each (Labarta, 2012).

Although several improved varieties have been officially released through the joint effort of CIP and NARIs, most of them have not been adopted by farmers (Shulte-Gildermann, 2013). Ethiopia released more varieties than other countries in SSA within the last decade. However, only a few of them are still being grown (Woldegiorgis, 2013; Kolech *et al*., 2015b). 'Local varieties', of unknown origin, still dominate in these countries (Kaguongo *et al*., 2008; Labarta *et al*., 2012; Kolech *et al*., 2015b). Local varieties are farmer varieties that have not been formally tested through variety selection procedures by breeding programs in SSA. These varieties were presumably

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developed through a farmer-driven process of evaluation and selection of varieties/clones introduced from outside sources. The percentage of total potato acreage planted to local varieties is about 73-77% in Ethiopia (Labarta *et al*., 2012; Kolech *et al*., 2015b), 70% in Kenya (Kaguongo *et al*., 2008) and 61% in Rwanda (Labarta *et al*., 2012).

Why has the adoption of new varieties in Ethiopia been so low? Why do most farmers and consumers prefer the widely grown, older, local varieties (Emana and Nigussie, 2011; Abebe *et al*., 2013, Kolech *et al*., 2015a)? Understanding the causes of low adoption of improved varieties by growers and consumers and a full assessment of available local varieties is an important first step for crop improvement in developing countries. Low improved variety adoption may be the case that there is a mismatch between the selection criteria that breeders and farmers use. Farmers often give more attention to yield stability, quality, and downstream uses than breeders do (Thiele *et al*., 1997). Another factor contributing to low adoption pertains to the country's tremendous variation in agro-ecologies and farming systems. Ethiopia's wide variation in altitude, temperature, rainfall, and soil types give rise to many unique agro-ecologies, which in turn give rise to the need for many different varieties. In addition, more than 62% of Ethiopian farmers grow potato in the unreliable dry seasons (Belmehr, Belg and Residual) (CSA, 2014), while the Ethiopian potato program has focused on variety development for the Meher season, when rainfall is dependable. According to Danial *et al*. (2007), the root cause of the limited success of breeding programs in the Andes is the high variability of environmental conditions and farmer preferences.

Few studies have been done to document the available local potato varieties and understand their uses in Ethiopia. Similarly, there have been few efforts to conserve and use local varieties as parents in breeding (Kolech *et al*., 2015a). The success of any plant breeding effort to provide varieties that are adapted to local abiotic and biotic stresses depends on a continual use of locally adapted varieties and wild relatives of closely related species for genetic enhancement (Padgham, 2009). As Bradshaw *et al*. (2006) noted, better adapted cultivars typically result from crosses between diverse sets of parents with complementary features, where at least one parent is adapted to local growing conditions. Varieties developed with the use of existing local varieties as parents are more likely to be adapted to local growing conditions.

Therefore, a set of research activities conducted in Ethiopia sought to: a) assess what traits farmers consider most important in different agro-ecological zones, in order to better guide future breeding efforts, b) document the specific characteristics, distribution, and area of adaptation of local potato varieties, c) assess tuber yields of selected local potato varieties across seasons and different agro-ecological settings and, d) examine the genetic diversity of Ethiopian potatoes and their relationship with clones developed in other parts of the world (CIP, America and Europe).

METHODS

Three hundred and twenty one randomly selected potato growers in six districts from northwest Ethiopia (Banja, Quarit, Yilmana, Laigaint) and South Ethiopia (Gumer and Geta and Shashemene) were interviewed during 2012 and 2014. These districts represent different agro-ecological zones and market access. The data collected

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included the names of local varieties they currently grow, the adaptation and characteristics of local varieties and proportions of farmers who grow these varieties. Moreover, focus group discussions were held in each district to support the data collected from semi-structured interviews. A list of farmers' variety selection concerns was compiled during the focus group discussions and from the answers that participants gave when asked about the positive and negative attributes of each variety in each district. Detailed methods are presented in Kolech *et al*. (2015a). Descriptive statistics and frequencies were calculated for the proportion of farmers who grew a variety in each district. The selection criteria compiled during the semi-structured interview is shown in Table 1.

Based on information from the survey of growers, the two districts in northwest Ethiopia (Yilmana and Laigaint) selected represent different agro-ecological zones, with different degrees of food security and market access, but share similar farming systems. Yilmana represents a moist agro-ecology (moist cool highlands) with good access to market outlets and better adoption of new varieties. In contrast, Laigaint represents a sub-moist (dry agro-ecology) with low access to potato markets but which nevertheless frequently receives potato seed (including new varieties) because of crop failures. The rainfall distributions in both districts are shown in Figure 1. A participatory variety selection (PVS) scheme, adopted from the Africa Rice Center (Africa Rice Center, 2010), was run in farmers' fields, with a design that enabled breeders and social scientists to evaluate variety yield and tolerance to biotic and abiotic stresses. Nine local varieties with diverse traits and three widely distributed new varieties were planted in two overlapping seasons ("Belmehr"- the principal season that farmers currently use for growing potatoes (March to August) and "Meher"- the season that the research system recommends for new varieties (May to October). A farmers' research group was organized in each district and the farmers who were separated into gender groups evaluated the varieties three times (at flowering, at harvest, and after three months in local storage structures). Farmers' variety selection concerns were recorded based on the comments they made during each variety's evaluation. A detailed description of the methods can be found in Kolech *et al*. (2015b). An Additive Main effects and Multiplicative Interaction (AMMI) model was adopted to construct biplots which partition the interaction effects of genotypes and environments. Genstat software (Genstat, 2013) was used for analysis of AMMI model.

Forty-four local varieties were collected from northwest and South Ethiopia (regions that together represent about 70% of Ethiopian potato production) and evaluated with 8303 SNP markers to reveal their genetic relationships. To supplement the molecular data, the 44 local varieties were also planted in a screen house at the Adet Agricultural Research Center and characterized for many morphological traits. The same SNP markers were used to cluster the 15 unique Ethiopian local varieties, 31 clones from CIP clones (17 improved varieties and 14 advanced clones), 17 varieties from Europe, and 22 varieties from North America. Unweighted pair group method with arithmetic mean (UPGMA)-based tree was constructed using the SplitsTree4 program version 4.13.1 (Huson and Bryant, 2006). The tree image was generated by Archaeopteryx version 0.9901 beta (Han and Zmusek, 2009). Detailed methods are presented in Kolech *et al*. (2016).

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Table 1: The most important potato traits across different agro-ecological zones and cropping seasons

District	State	Agro-ecology and other variables	Cropping season	Most important traits
Banja	Amhara (Northwest Ethiopia)	Sub-humid cool highland, 2560 m altitude, low access to markets, little effort to introduce new varieties	*Belmehr (rain-fed)	Drought tolerance, late blight resistance, long storability, suitable for boiling and stew
			Belg (irrigation)	High yield with early bulking, suitable for boiling and stew
			Residual (rain-fed)	Drought tolerance, suitable for boiling and stew
Laigaint		Sub-moist (dry) cool highland, 3100 m altitude, low access to markets, moderate effort to introduce new varieties	*Belmehr (rain-fed)	Drought tolerance, long storability, suitable for sequential harvesting, tolerant of low fertility soil, suitable for boiling and stew
			Belg (irrigation)	High yield with early bulking, suitable for boiling and stew, good market trait (medium to large tuber size)
Quarit		Moist cool highlands, 3050 m altitude, low access to markets, little effort to introduce new varieties	*Belmehr (rain-fed)	Drought tolerance, long storability, suitable sequential harvesting, tolerant of low fertility soil, suitable for boiling and stew
			Belg (irrigation)	High yield with early bulking, good market trait (medium to large tuber size)
			Residual (rain-fed)	Drought tolerance, suitable for boiling and stew
Yilmana		Moist mid highland, 2500 m altitude, high level of market access, and moderate effort to introduce new varieties	*Belmehr (rain-fed)	Drought tolerance, late blight resistance, insect resistance, long storability, good market traits (suitable for stew and medium to large tuber size)
			Belg (irrigation)	High yielding with early bulking, suitable for boiling and stew, good market traits (suitable for stew and medium to large tuber size)
Shashemene	Oromia	Sub-moist mid highland with bimodal rainfall, 2000 m altitude, very high level of market access, low adoption of new varieties	*Belg (rain-fed)	Drought tolerance, market traits (white color, good stew quality), short dormancy but good storage quality
			Meher (rain-fed)	Drought tolerance, late blight resistance, short dormancy, good market traits (indicated above)
Gumer and Geta	South	Moist cool highland with bimodal rainfall, 2800-2850 m altitude, high seed market for new varieties, high rate of new adoption variety	*Belg (rain-fed)	High yield, suitable for boiling
			Meher (rain-fed)	Good late blight resistance, good tolerance to severe precipitation, long storability, suitable for boiling

*Currently the most important production season for potato in that district

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RESULTS AND DISCUSSION

Identifying potato traits important to farmers

Potato traits important to farmers in selected districts of Ethiopia representing varied agro-ecological zones and degrees of market access were identified using two study approaches (growers' survey and PVS). Key traits were identified by collating the responses farmers gave about the positive and negative attributes of each of the varieties they have had direct growing experience during the survey, as well as their views of the varieties tested in the PVS experiment. Table 1 summarizes the most important potato traits across six agro-ecological zones, as compiled during the growers' survey, while Table 2 presents the relative importance of traits, as determined from the responses of farmers during the PVS experiment.

From the two studies, it was clear that farmers considered 23 traits important for variety selection. During the PVS experiment, farmers were asked to rank these traits, in three different categories, for importance to them (Table 2). The three categories: i) suitability for consumption and the market, (ii) tolerance to biotic and abiotic stresses, and (iii) agronomic traits. Of the 23 traits, nine were considered very important by more than 70% of the farmers spoken to in both agro-ecologies (Table 2). The nine traits are suitability for use as boiled potato, suitability for use in preparing stew, market demand, late blight resistance, drought tolerance, tolerance to desiccating wind and heavy precipitation, high yield, long shelf life and suitability for sequential harvesting. Even so, the degree of importance of these traits differed by agro-ecological zone, cropping season, degree of market access, and in a few cases, gender (Table 1 and 2). The remaining 14 traits either had lower importance or were related to the nine most important traits. For example, long root and stolon system is related to sequential harvesting, while thick stems and leaf strength are related to tolerance to strong wind and heavy precipitation. Tuber spoilage tolerance in storage is partly related to storability traits. Several other traits are related to yield such as plant height during seasons with good rainfall. Early maturity was not included among the most important traits list in either agro-ecological zone in northwest Ethiopia during the Belmehr cropping season, probably because the choice of variety to be planted is determined based on rainfall distribution, a variable that was not controlled. If there is early onset of rainfall, farmers want to plant late maturing varieties and *vice versa*.

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Table 2: Percent of farmers rating traits as "very important"

Traits	Laigaint			Yilmana		
	Male	Female	Both	Male	Female	Both
Agronomic traits						
Long root system	50.0	42.9	46.4	10.7	0	5.3
Large plant height	15.0	14.3	14.6	0	0	0.0
High yield	100	100	100	100	100	100
Large leaves	40.0	28.6	34.3	17.9	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
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
Utilization						
Suitability to boiling potato	100	92.9	96.4	100	100	100
Suitability to 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

Ethiopia has a unique and tremendous agro-ecological and edaphic conditions that are suitable for potato production. However, several production constraints, which vary among agro-ecological zones (Kolech *et al.*, 2015a) limit yield. Table 1 compiles the traits that farmers consider most important for each agro-ecological zone and growing season. The availability of different local varieties in each of the agro-ecologies is consistent with the variation observed in farmers' variety selection concerns; if all regions in all of the seasons had the same constraints, they would all grow the same varieties. The results of the growers' survey also showed that farmers' variety selection concerns differed among cropping seasons (Table 1). A graphical depiction of each growing season in two major agro-ecologies is shown in Figure 1. The degree to which farmers valued drought tolerance, late blight resistance, tuber maturity and early bulking, tolerance to heavy precipitation and tolerance to desiccating wind and low soil fertility tolerance, differed among agro-ecologies and growing seasons. The importance of each of the traits in each agro-ecology and cropping season is described below.

Suitability to different food uses and target markets

The difference in food habits between urban and rural households leads to differences in variety requirements. City dwellers primarily consume potato as "Alicha", which is a stew mixed with vegetables where the cooked tuber should be firm, while rural households mostly consume potato that has simply been boiled. Other uses of the crop worldwide as French fries, chip and others were not common in the study districts. Whether or not a potato is destined for the city markets has a significant influence on what traits it needs to possess. Thus, stew quality is more important for these markets than boiled quality. Stew quality includes resistance to tuber bruising (so the potatoes can easily be transported), remain firm during cooking, and desirable tuber size (medium to big tubers) are important factors if a variety is to be sold in food markets. Skin color is an important trait that determines the acceptance of a variety in markets in Shashemene. Because consumers in Addis Ababa and neighboring cities and towns never accept red skinned tubers, more than 98% of Shashemene farmland was planted to white skin varieties (Kolech *et al*., 2015a). In contrast, varieties that are sold in rural markets mostly need to be suited for boiling; skin color is not especially important. A good potato for boiling should have good taste when boiled, resistant to greening and desirable tuber size. Farmers can grow varieties that are good for stew but not necessarily suitable for boiling because bitterness can be masked in stews. For instance, framers in Yilmana grow 'Sisay', a new variety, commonly for market purpose (good for stew) but not for their consumption (not good for boiling).

Storability

Storability is an important trait in most of the agro-ecologies (Table 1 and 2). Long storability in storage structures as well as in-field storage are important to farmers in all agro-ecological zones except Shashemene. Outside of Shashemene, majority of farmers grow potato for their own consumption, and want to store much of their production for future use. The growers' survey showed that all farmers in northwest Ethiopia and close to 70% of farmers in Gumer and Geta employ 'in-field storage' (delayed harvesting). In this system, mature potato tubers are left unharvested for 4-5 months, then stored in the dark either heaped in a ventilated condition or in underground pits. The local varieties in northwest Ethiopia and a new variety Gudene (in Gumer and Geta), are suitable for such storage. The PVS experiment also revealed the importance of storability, as more than 95% of farmers in both moist and sub-moist agro-ecological zones of northwest Ethiopia considered the trait to be very important. Although long storability is an important trait for farmers in Gumer and Geta, they mostly grow local varieties that cannot be stored for long. However, these local varieties are gradually being replaced by a new variety, 'Gudene', that can be stored for longer periods. In contrast, farmers in Shashemene need varieties with short dormancy so that they can grow crops in two consecutive growing seasons (Belg and Meher).

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Traits Unique to Agro-ecological Zones

Suitability for sequential harvesting (more than one harvest in the same growing season) is an important trait in sub-moist (dry) agro-ecology. Our PVS study showed that although sequential harvesting (which is related to providing food for a long period of time) is important for moist cool highlands (Yilmana), more than 95% of the farmers in the sub-moist cool highland (Laigaint) consider this trait to be very important. Existing local varieties with long stolons provide this trait for this agro-ecology.

Tolerance to low fertile soil is another important trait in sub-moist (dry) agro-ecology. The soil analysis result in the PVS experimental sites in this agro-ecology showed that important nutrients such as nitrogen, phosphorus and potassium are at levels considerably below those recommended for crop production (Kolech *et al*., 2015b). Because of erratic and uneven distribution of rainfall in this agro-ecology, even during the main rainy season, applying chemical fertilizers is a challenge because plant roots cannot access the fertilizer when the soil is dry. Thus, farmers in this agro-ecological zone prefer varieties adapted to low fertile soil.

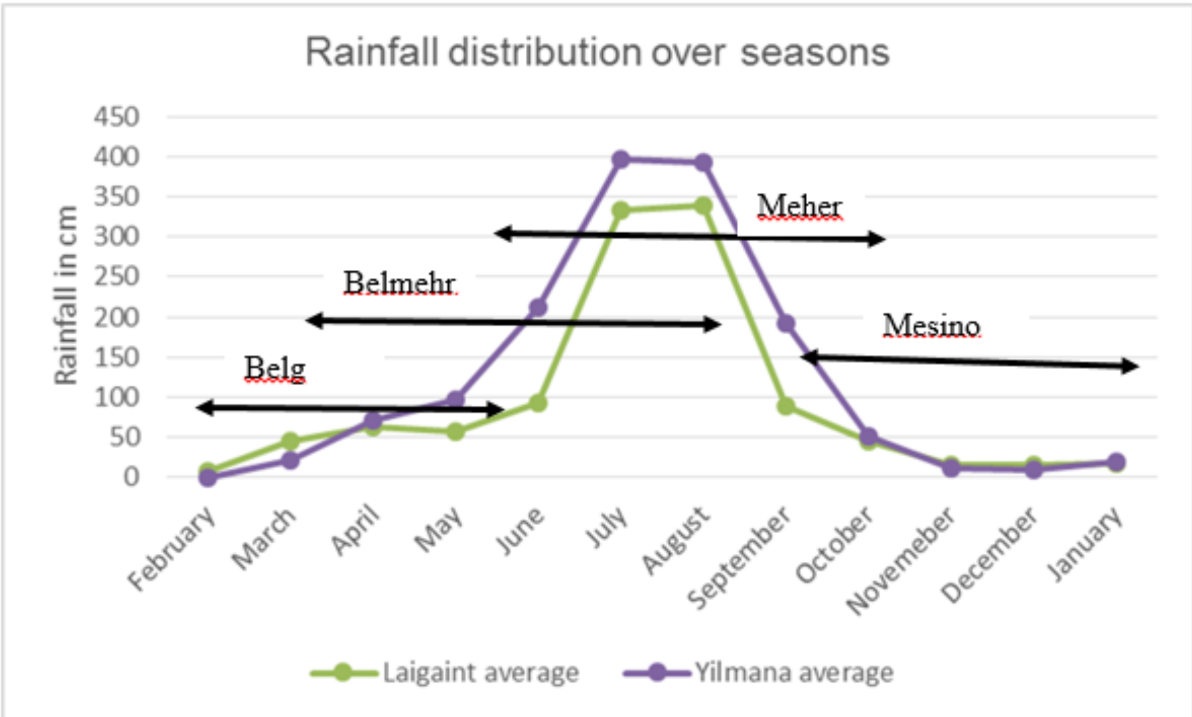

Figure 1: Rainfall distribution at four growing seasons (Belg, Belmehr, Meher and Mesino) in moist cool (Yilmana) and sub-moist cool (Laigaint) agro-ecological zones

Late Blight Resistance

Based on the growers' survey, late blight is a major production constraint in the Meher season in Gumer and Geta and also in Shashemene. Indeed, 88% and 95% of the sampled farmers in Gumer, Geta, Shashemene and Addis Ababa, respectively, spray fungicide to protect the disease in the Meher season. The same farmers do not spray their crop in the Belg season. In northwest Ethiopia, all farmers grow potato in the dry seasons, and none of the farmers spray their crop for late blight. Some of the farmers studied in this region, with the support of the research system, grow late blight resistant, early maturing new varieties in Meher season and do not spray their crop. Because the end of the Belmehr season overlaps with part of the main rainy season, late blight can damage the crop as it nears maturity, especially in moist mid highland agro-ecology (Yilmana), and yields are often reduced. Late blight susceptible local varieties (such as 'Abalo' and 'Samune') are gradually being replaced by late blight resistant local varieties ('Siquare') in moist mid highlands of northwest Ethiopia (Yilmana) and sub-humid cool highlands (Banja). Therefore, for farmers who grow potato in the Meher season (for any of these agro-ecologies) and Belmehr season (mainly for moist mid altitude and sub-humid cool agro-ecologies in northwest Ethiopia), late blight resistance is a very important trait.

Selected Abiotic Stress Tolerance

The importance of abiotic stresses such as drought, heavy precipitation and desiccating wind varied among seasons. Unsurprisingly, farmers reported that drought tolerance is more important for dry season production (Belmehr, Belg and Residual) rainy season production. Varieties that can tolerate water stress are especially critical for Belmehr production because rain may not fall in early or mid-stages of the plant growth cycle. Local varieties with long roots such as 'Abalo' can fit Belmehr production if rain starts early in the growing season.

According to the farmers we surveyed, rainfall intensity (amount of rainfall per unit time) is increasing over time in the Meher season, especially in moist agro-ecologies. Hail is common especially in northwest Ethiopia. Desiccating wind is also a major limiting factor for parts of Meher season (end of August to September); it causes plants to lodge before maturity. Based on the PVS experiment and the researcher's observations, thick stems and strong leaves appear to be important traits that help reduce damage from wind and heavy rain. These traits also appear to confer tolerance to hail damage. The new varieties 'Gudene' and 'Belete' have relatively big stems and strong, tough leaves and exhibit good tolerance to wind, rain and hail. Most of the older local varieties, including the widely grown variety 'Siquare' are susceptible to damage from these abiotic stresses.

Maturity Trait

Maturity is another trait whose importance varied among growing seasons. Early maturity is much more valued in Meher, Residual and Belg seasons than in Belmehr. Since an early conclusion of rainfall is a characteristic of Meher season production, especially in sub-moist agroecology, only 2 rainy months are available for the growth of the crop. Therefore, early maturity is a useful trait if potato is to be grown in this season. The available new varieties with early maturity are good choices for this season. The Residual planting season is an important growing season in moist and sub-humid cool highlands of northwest Ethiopia and immediately follows the main rainy season (Meher). Potato and barley are the dominant crops in this season, and make use of residual moisture from the main rainy season. Since soil moisture is only adequate

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for the first 30-45 days, an early bulking trait is also important for this production season. Early maturity is also useful for Belg season production under rain-fed and irrigated conditions. For the Belmehr season, desired maturity is a function of when rain first falls. If there is early onset of rainfall, farmers plant late maturing varieties such as 'Abalo' and 'Samune'. If rain starts late, they plant early maturing varieties such as 'Siquare' and 'Sisay'. It is in part for this reason that farmers keep a set of diverse varieties at hand. Since farmers store both seed potatoes and ware potatoes in the same storage structures, a variety that is not used as seed is used as food.

Trait Value by Gender

In the PVS experiment, groups of women and men farmers separately evaluated local and new varieties at three time points: at flowering, harvest, and three months after storage. In each evaluation, farmers were asked to identify the best five and the worst five varieties, giving their reasons. We recorded these reasons as variety traits. Then, individual farmers from each group were asked to rank these traits, as summarized in Table 2.

In most cases, the selection criteria of the women farmers matched those of the men . Of the 23 traits listed by both genders, only three varied considerably by gender (Kolech *et al*., 2015b). This shows that both men and women farmers value many of the same traits, and that improvement in these traits can benefit all farmers equally. Only in the Laigaint area were gender differences observed, and only for these traits: adaptation to low soil fertility, long roots/stolons and market demand. Although these traits are important for both men and women, adaptation to low fertile soil and market demand were more important to men than to women, while long roots/stolons, and associated suitability for sequential harvesting, were more important for women. The Laigaint area is characterized by poor soil fertility and erratic rainfall, so that poor productivity and food insecurity are frequent in this agro-ecology (Kolech *et al*., 2015b). Due to the erratic nature of the rainfall, chemical fertilizers are not always useful. Thus, the only option is to use varieties that tolerate low fertile soil and erratic rain. Men farmers may have been more concerned about market demand than women farmers because more of the men were heads of households, and thus felt more responsibility than women in resolving financial constraints. In contrast, the women farmers were more concerned with traits that supply food for a longer period of time. A long root/stolon system facilitates sequential harvests of the crop during the "hungry months", July-August, when other crops are not yet ready for harvest.

Characteristics and adaptation area of widely grown local varieties

As summarized in Table 3, farmers choose varieties for different purposes including storability, drought tolerance, late blight resistance, marketability traits, and suitability for boiling and stew. Unsurprisingly, farmers pay attention to specific characteristics when deciding which varieties to grow, so they can meet specific production challenges and end-use needs.

All of the local varieties in Northwest Ethiopia can be stored successfully for long periods both in above-ground storage structures and in-field (unharvested). According to respondent farmers and PVS results, 'Abalo' is preferred in cool highlands of

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northwest Ethiopia for its long storability, suitability for boiled potato and stew, drought tolerance, adaptation to low fertility, and fit to sequential harvesting. 'Siquare' is the most widely grown local variety in Northwest Ethiopia and dominates markets in major towns in this region. Our molecular characterization showed that this variety is also grown in south Ethiopia, but under a different name ('Key'). Farmers prefer to grow 'Siquare' because it is early maturing, has good marketability and good tolerance to late blight. 'Samune', another northwest local variety, has good storability and is preferred for its food value (suitable for boiled potato). But, due to its susceptibility to late blight, its production is decreasing. The demand for "Abateneh", a late maturing variety in northwest, is increasing due to its late blight resistance, suitable for long storage, good for boiling and has good market demand. Although, 'Abadamu', another northwest local variety, has attractive tuber size and suitable for long storage, because of its bitter taste, its production is very limited. 'Abalo' and 'Abateneh' are late maturing varieties that are suitable for Belmehr season production in northwest Ethiopia.

In contrast to northwest varieties, the local varieties from South Ethiopia ('NechAbeba', 'Agazer', 'Holland', 'Key Dinch') have short dormancy and cannot be stored for long periods. 'Agazer' and 'NechAbeba' are early maturing and perceived to have good taste. They are high yielding, suitable for both boiled and stew potato, have good market demand. 'Agazer' has better demand than 'NechAbeba' because of its good storage quality, very early maturing and suitable for distant markets. 'Bulle local', another variety in southern Ethiopia, because of its purple color, its demand is limited to local markets.

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Table 3: List of Ethiopian local varieties and their specific characteristics

Widely known name*	Other names	Drought tolerance	Sequential harvesting	Adaptation to Poor fertile soil	Late blight resistance	Long Store ability	High yield	Early maturity	Late maturity	Boiled potato	Stew	Market demand
Abalo (NW)	Bayle Lakew	+	+	+		+		-	+	+	+	
Samune (NW)	-					+		-	+	+	+	
Siquare (NW)	Key dinch, Miritzer, Deme, AterAbeba, Key				+	+		+	-	+		+
Abadamu (NW)	Abalo large	+				+					+	
EnatBeguaro (NW)	Agere		+	+		-		-	+	+	+	
Abateneh (NW)	RejimSiquare				+	+		-	+	+		+
Kuchibiye (NW)	Ayito					-						
Agazer (SE)	DurameShule	+			+	-	+	+	-	+	+	+
NechAbeba (SE)	Nech					-	+			+	+	+
Durame (SE)	Asmera					-				+		
Key Shule (SE)	Key Abeba, Achire China							+	-			
Feleke (SE)	Akime		+			-		-	+			
Bulle Local (SE)	Fayzer, Key Dinch					-				+		
Gedigala (SE)	Nech					NI				+		
Holland (SE)	-					-		+	-	+		

* NW and SE denote varieties from northwest Ethiopia and South Ethiopia respectively; "+"denotes a strong relationship between the variety and the trait while "-"shows a negative relationship of the variety with the trait. "NI" denotes no information about the variety with the traits considered

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The growers' survey showed that nine cultivars (six local and three improved) were widely grown across districts. 'Siquare', 'Abalo', 'Samune', 'Agazer', 'NechAbeba' and 'Holland' were widely grown local cultivars while 'Gudene', 'Jalene' and 'Sisay" were the most widely grown improved varieties in our survey districts (Table 4). Eleven cultivars, six of which are local, were grown by few farmers. Growers reported that eight cultivars have been lost while an additional 12 were considered rare/near extinction. However, we noticed that some cultivars that were recorded as rare or abandoned in one area were widely grown in other districts. For instance, 'Samune' is widely grown at Banja but abandoned in the Shashemene area, whereas 'Bulle local' is widely marketed near Shashemene but rare on farms in Shashemene and surrounding areas.

The local varieties 'Siquare', 'Abalo' and 'Samune' are grown by many farmers in northwest Ethiopia (Table 4). 'Siquare' is predominantly grown in Quarit, Yilmana and Banja districts in this region. 'Abalo', the second important variety, mainly limited to cool highlands above 2600 m.asl. It is a predominant variety in sub-moist cool agro-ecology (Laigaint). 'Samune' is only grown as a local variety in sub-humid cool agro-ecological zone (Banja district) where acid soil is prevalent. 'Sisay', an improved variety, is grown by 80% of the farmers in the Yilmana district of northwest Ethiopia. A local variety, 'Abateneh', and some improved varieties such as 'Jalene'', 'Belete', 'Gudene', 'Gera' and 'Tolcha' are grown by a few farmers in this part of Ethiopia. In south Ethiopia, local varieties such as 'Agazer', 'NechAbeba' and 'Holland' ('Hosana') are widely grown (Table 4). 'Agazer' and 'NechAbeba' are popular varieties in Shashemene and surrounding areas while 'Holland' is widely grown in Gumer and Geta. 'Key Dinch' and 'Jibut' are also grown by a few farmers in Shashemene. In Gumer and Geta, unlike other study districts, potato production is dominated by improved varieties. More than 90% of the farmers here grow improved varieties (Table 4). Five different local varieties are grown but 'Holland' is more important than the others. More than half of the surveyed farmers grow 'Holland'.

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Table 4: Proportion of farmers who grew major potato varieties in Ethiopia

Variety	Source	Shashemene	Quarit	Yilmana	Laigaint	Banja	Gumera and Geta
Agazer	Local	100	0	0	0	0	0
NechAbeba	"	60	0	0	0	0	0
Key Dinch	"	17.5	0	0	0	0	0
Jibut	"	5	0	0	0	0	0
Abalo	"	0	76.2	45	100	0	0
Siquare	"	0	95.2	100	55	100	0
Samune	"	0	0	0	0	90	0
Abateneh	"	0	9.5	0	0	0	0
Holland	"	0	0	0	0	0	56.2
Ajamazer	"	0	0	0	0	0	18.7
Key Tolch	"	0	0	0	0	0	9.4
Asefu	"	0	0	0	0	0	8.7
Askot	"	0	0	0	0	0	3.7
Jalene	Improved	10	0	0	22.5	0	87.5
Gudene	"	10	0	0	5	0	91.2
Belete	"	0	0	0	15	0	22.5
Tolcha	"	0	0	5	0	1	0
Gera	"	0	0	10	0	0	0.6
Guasa	"	0	0	0	0	1	4
Sisay	"	0	0	80	0	0	0
Sample size		40	21	20	40	40	160

Seasonality and Performance of Local Varieties

Although rainfall is not dependable for growth of the crop, farmers in northwest Ethiopia prefer to grow potato in the dry season for several reasons (Kolech *et al.*, 2015a). First, farmers plant potato in Belmehr (dry season) so they can harvest it during July and August (the so-called hungry months) to augment a gap in food availability. Second, Belmehr season production enables farmers to grow two crops at once using intercropping. More than 50% of the farmers in the Yilmana and Quarit districts of the Amhara region (northwest Ethiopia) practice intercropping of potato with other crops, mainly maize (Kolech *et al.*, 2015a). However, the research recommended planting time for improved potato varieties is Meher, the main rainy season. Although local varieties have excellent cooking and eating qualities (suitable for boiled potato and stew) and are in high demand by farmers (Abebe *et al.*, 2013; Kolech *et al.*, 2015a), they can't easily be grown in the main rainy season due to late blight pressure (Bekele and Eshetu, 2008; Kolech *et al.*, 2015b).

Based on the result of the field experiment in PVS study, Meher season production challenges include hail and heavy rain, late blight, desiccating wind, and late onset drought while erratic rainfall was the main limiting factor for Belmehr season production. Thus, the performance of local varieties differed between the two cropping

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seasons. The AMMI plot analysis shows that all of the late maturing local varieties ('Abalo', 'EnatBeguaro', 'Rejim China', 'Feleke') fit well to the Belmehr season, while early bulking local varieties such as 'Siquare' and 'Abadamu' performed better in the Meher season. Several local varieties ('Abadamu', 'NechAbeba', and 'Rejim China') yielded as well as improved varieties in both seasons when disease free seed was used (Kolech *et al*., 2015b). This finding negates the previous belief that Ethiopian local varieties have low yield potential (Kidane-Mariam, 1979). Most of the improved varieties are well suited to Meher season production (short growing season) due to their early maturity, late blight resistance and tolerance to desiccating wind and hail damage (they have thick stems and good leaf strength). That some of the early maturing local and new varieties also yielded well during the Belmehr season may be because of favorable rainfall distribution in these specific trials. Thus, further study is required to see if these varieties can consistently perform well in Belmehr.

Genetic Diversity and Similarity among Ethiopian Local Varieties

As the SNP analysis made clear, 34% of the 44 local varieties collected were unique, while the rest are duplications known by different names. For example, one widely grown local variety, 'Siquare', is known by six different names in different areas of the country. The names of local varieties are typically based on characteristics that farmers readily perceive, such as taste, texture, flower and tuber color, or productivity. The duplications presumably misled previous authors that assumed each name represented a different genotype (Tesfaye *et al*., 2008; Labarta *et al*., 2012; Yazie *et al*., 2011). Having a unique name for each unique genotype is important for future variety identification, research and breeding activities. Common names for Ethiopian local varieties are shown in Table 3.

Genetic diversity and relationship of Ethiopian local varieties with European, North American and CIP clones

Neighbor joining analysis of European, North American, CIP and unique Ethiopian clones revealed three groups: Group I, where all North American clones clustered; Group II, where most European clones clustered; and Group III, where all CIP clones clustered. Some Ethiopian clones were clustered in Group II, others in Group III. Several publications reported that Ethiopia imported several potato varieties from European countries before late 1980s (Kidane-Mariam, 1979; Yilma, 1986). Thus, the simplest interpretation is that Ethiopian clones in Group II are descended from European germplasm, while Ethiopian clones in Group III are primarily of CIP origin. At a minimum, the distinct groupings of local varieties suggest that current Ethiopian local varieties represent at least two distinct introductions.

Within Group II there are two sub-clusters. The older local varieties 'Abalo', 'Samune', 'EnatBeguaro' and 'Durame' are in one sub-cluster, while the younger 'Siquare', 'Gedigala', 'Fekeke' and 'Key Shule' are in the other sub-cluster. Group III can also be divided into two sub-clusters. All of the varieties except 'Abateneh' are in the same sub-cluster. All southern varieties and one variety from northwest Ethiopia, 'Abadamu', are grouped in the larger Group III sub-cluster. The most widely grown local varieties in northwest Ethiopia ('Siquare', 'Abalo' and 'Samune') are all in Group II; these varieties represent about 85% of potato acreage in northwest Ethiopia (Kolech

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et al., 2015a). In contrast, the predominant local varieties from south Ethiopia (‘Agazer’, ‘NechAbeba’, ‘Holland’ and ‘Bulle local’) are all in Group III.

Even though Ethiopian local varieties did not exhibit any unique marker alleles, they exhibited levels of heterozygosity comparable to other world germplasm (Kolech *et al*., 2016). Indeed, the lack of unique marker alleles may well reflect ascertainment bias, as the SNPs used for genotyping were originally selected for their ability to differentiate North American varieties. Thus, Ethiopian local varieties harbor considerable genetic variation that can provide a foundation for future potato breeding. Current SNP data did not support the view that Ethiopian local varieties have a narrow genetic base (Kidane-Mariam, 1979).

CONCLUSION

From both the grower survey and PVS studies, it was clear that the traits that farmers consider to be most important are very diverse and vary among agro-ecological zones, cropping seasons, market access and, in a few cases, by gender. Such a diverse array of grower requirements among agro-ecological zones, cropping seasons and market access will prove challenging for breeders. Focusing only on late blight resistance, broad adaptation and high yield is unlikely to address all current needs. In other words, developing a single variety suitable for all agro-ecological zones and cropping seasons is practically impossible in a country with such tremendous environmental and socioeconomic variation. The low adoption of new varieties in Ethiopia is likely due, at least in part, to not addressing the myriad needs of growers and consumers. Addressing variety needs imposed by variation in agro-ecological zones, cropping seasons and market access during breeding is vital if varieties are to be developed that truly meet farmer and consumer needs. A national Ethiopian breeding program that evaluates candidate varieties in multiple agro-ecologies is certainly warranted, although it will likely be necessary to focus their efforts on specific target environments.

As to the farmer’s variety traits, both the PVS study and the growers’ survey revealed that the distribution of local varieties varies across agro-ecologies, cropping systems, and degree of access to external markets. Late blight susceptible local varieties are common in the cool highlands while moderate late blight resistant varieties are grown in both cool highlands and mid highlands with moist agro-ecology. Varieties with market-preferred traits dominate in areas such as Shashemene that have high market access.

Our PVS study in two distinct growing seasons in northwest Ethiopia showed that varieties perform differently between seasons. Late maturing local varieties are well-adapted to the Belmehr season, a long season with erratic rainfall. Most improved varieties are well-adapted to the main rainy season because they have good resistance to late blight disease and good tolerance to severe precipitation and desiccating wind. Of note, some local varieties yielded as well as the best performing new varieties when late blight severity was low.

The genetic diversity study revealed that there were only 15 unique varieties grown in northwest and south Ethiopia. Some of these varieties were most closely related to

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varieties of European origin, while others were most closely related to varieties from CIP, suggesting at least two origins for local varieties. Therefore, these local materials provide a useful starting point for the development of improved varieties, as they carry versions of genes that meet many needs. Preparing an Ethiopian potato catalogue that includes local varieties will help to raise their visibility, and ensure that they are known by the same name all over the country.

As in Ethiopia, local varieties in other East African countries are likely to provide useful traits for modern breeding. Indeed, most east African countries would benefit by initiating their own crossing and selection programs, in addition to evaluating clones that CIP currently provides. Varieties selected from the earliest stages in East Africa are likely to be better adapted to the local environment including temperature, rainfall, and soil type, but also the cultural preferences of growers and consumers.

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