

## Genotypic Variation in Potato Growth and Yield Response to Water Stress During two Production Seasons in Northwest Ethiopia

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### Abstract

*Water stress during low-rainfall periods (Mesino and Belg) constrains the potato from meeting full yield potential in northwest Ethiopia. Farmers tend to grow local varieties in these seasons but these varieties have not been tested for their water stress tolerance. 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. Nine local varieties and six new varieties were tested in the screen house at Adet Agricultural research center in both Mesino and Belg seasons for their response to moderate water stress conditions during 2014. All varieties were grown under two water regimes (well-irrigated and stressed) maintained by monitoring soil moisture. The results showed that, averaging across varieties, the marketable tuber yield losses due to water stress in Mesino (residual production) and Belg seasons were 28% and 67%, respectively. Substantial differences between varieties in growth and yield response to both growing season and water stress were also observed. In the Mesino season, although no variety out-yielded the main local variety, 'Siquare', under drought conditions, "Belete", "CIP-395109.34", "Abadamu" and "Granola" had showed the lowest water stress susceptibility index (SSI) and higher marketable tuber yield in stress condition. In the Belg season, 'Granola' followed by 'Abadamu' and "Gera" had the highest marketable tuber yields under both irrigated and stress conditions and the lowest water stress susceptibility index. Traits associated with high marketable yield potential and stability under stress condition include: high harvest index, increased root length, relatively few deformed and small sized tubers under stress. The results indicated potential for improving dry season potato production in Ethiopia by utilizing both selected local and new varieties.*

**Keywords:** Local varieties; Growing seasons; Stress susceptibility Index; Drought Conferring Traits

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### 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 (Kolechet *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. Also, dry season potato production can fill a critical food gap during the “hungry months” (Kolechet *et al.* 2015).

While potato is generally considered a drought-sensitive crop (Lalouet *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 (Kolechet *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 varies depending on the duration and severity of the stress in relation to the plant’s phenological stage (Jefferies, 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) 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) identified ‘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.

Most of the farmers who grow potato in Ethiopia in the dry season grow local potato varieties. The use of improved varieties is not common in low rainfall seasons.

Ethiopian potato growers reported preference for selected local varieties under drought conditions (Kolechet *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.

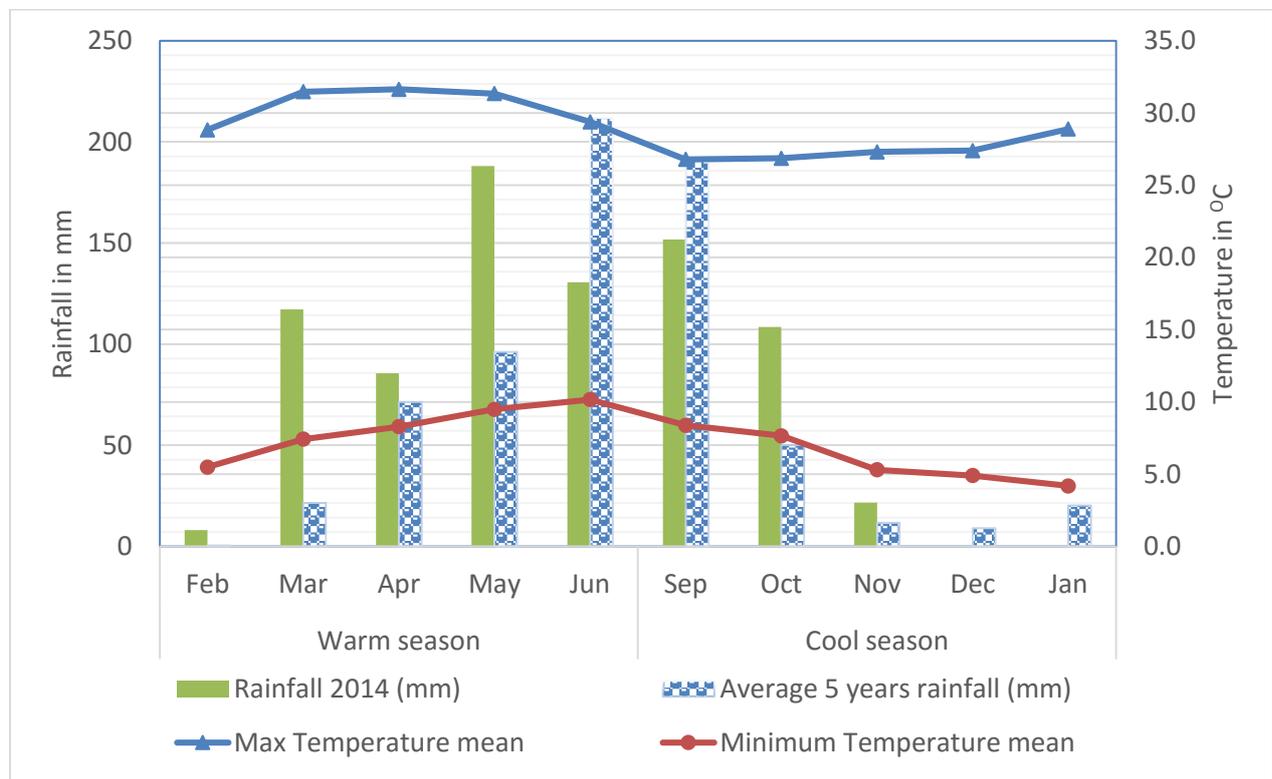
## **Material and Methods**

### ***Experimental site and planting seasons***

The experiment was conducted in a greenhouse at the Adet Agricultural Research Center, near Bahir Dar, Ethiopia (elevation 2200 m.), targeting two growing seasons, the Belg (from Feb 21 to June 18) and Mesino (from October 3 to January 23). The Belg (warm) short-rain season is relatively warm and typically begins at low

soil moisture followed by increasing, but erratic and undependable rainfall so that supplemental irrigation is a necessity. Planting potato for the Mesino (cool) 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. 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. The historical average minimum and maximum temperatures (average of temperature for the last five years) and rainfall of the site in both growing seasons are shown in Figure 1.



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

### Varieties Evaluated

Nine local potato varieties were in this study. 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 screen house for inclusion in the experiment. 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 1.

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

Varieties	Origin	Maturity	Storability	Adaptation areas
Key Shull	Local collection	Very early	poor	Shasho District, SNNP region
Square	“	Early	good	NW Ethiopia
Agazer	“	Early	good	SNNP and Oromia regions
NechAbeba	“	Medium early	poor	SNNP and Oromia regions
Abadamu	“	Medium early	excellent	Quarit District, NW Ethiopia
Bulle	“	Medium late	poor	Kofele district, Oromia region
EnatBeguaro	“	Medium late	poor	Sinan District, NW Ethiopia
Rejim China	“	Late	poor	KofeleDistrict, Oromia region
Abateneh	“	Late	medium	Quarit and Sekela, NW Ethiopia
Granola	European variety	Early	good	<a href="http://www.solana.de/news">http://www.solana.de/news</a>
CIP-395109.34	Advanced clone	-	-	-
Sisay	Improved variety	Early	good	Yilmana, NW Ethiopia
Gera	“	Early	good	Adapted to dry areas above 2700 m.asl
Belete	“	Early,	medium	widely adapted variety
Jalene	“	Medium early	poor	widely adapted variety in Ethiopia

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

### **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 (133 kg ha<sup>-1</sup>) 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.

### **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),

estimated total plant leaf area, and maximum root length. Green leaf color index data were collected with a SPAD meter (SPAD-502, Minolta, Japan). 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 70°C 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). The specific leaf weight (SLW) was calculated as leaf dry mass per unit leaf area.

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 70°C 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). Stress susceptibility index (SSI) was computed for both marketable and total yields as described by Hassanpanah (2010):

$$SSI = (1 - Y_{si}/Y_{pi}) / (1 - Y_s/Y_p),$$

Where  $Y_{si}$  and  $Y_{pi}$  are the dry weight yield of variety “i” under stress and normal conditions, respectively, and  $Y_s$  and  $Y_p$  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.

### 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, Specific leaf weight, 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).

## Results and Discussion

### Seasonal Effect on Drought Tolerance Ability of Potato Varieties

Season main effect on plant height, above ground biomass, root length, SPAD reading, number of tubers per plant, total and marketable tuber yield, and HI were statistically significant at  $p < 0.05$  (Table 2). Averaging across irrigation treatment and variety, plants grown in the cool Mesino season were in general more productive, with higher HI than in the relatively warm Belg season. Although high foliage growth in the warm (Belg) growing season (Table 3), HI was reduced for all varieties, which is expected as tuberization of potato is reduced at warm temperatures (Menzel, 1980).

Better marketable and total tuber yields and lower unmarketable small, deformed and green tubers were recorded in Mesino than the Belg season (Table 4, 5). However, higher SPAD readings (or green color index), above ground biomass and total

tuber number per plant were observed in the Belg season than that of Mesino (Table 3). Higher SPAD readings in the warm Belg season might be due to quick water loss in leaves associated with high foliage growth in these pot plants. According to Martinez and Guamet (2004), SPAD readings increased in slightly dehydrated leaves due to increase in light reflectance and a decrease in apparent transmittance.

Averaging across varieties, the marketable yield reductions due to water stress were 28% and 67% in the Mesino and Belg seasons, respectively (Table 4). There was also a greater decline in HI (Table 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 2). Similarly, the SPAD readings, a green color index associated with chlorophyll per unit leaf area (Barraclough and Kyte 2001), also increased under stress (Table 3). This shows that the impact of drought in the Belg season is more severe than that of Mesino

Table 2: Analysis of variance results for selected data

Parameter	PH	RL	SD	AGB	MTY	TTY	TTN	HI
Season	**	**	**	**	**	**	**	**
Watering regimes	**	**	**	**	**	**	NS	**
Variety	**	**	**	**	**	**	**	**

Watering regimes* Variety	NS							
Season*Watering regimes	**	NS	*	NS	NS	NS	NS	**
Season*Variety	**	*	*	**	**	**	**	**
Season*Watering regimes *Variety	NS							

Water regimes, I= well irrigated; S= stressed; PH= Plant height in cm; RL= Root length; SD= SPAD reading; AGB= Above ground biomass; MTY= Marketable tuber yield (g/plant); TTY= Total tuber yield; TTN = Total tuber number/plant (g/plant); HI= Harvest Index\* Significant at the  $P$  0.05 level; \*\* Significant only at  $P$  0.01 NS-non significant.

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 all of the parameters measured (Table 2).

All of the tested genotypes gave by far better marketable tuber yields in Mesino season than the Belg season (Table 4). Although some varieties such as ‘Granola’, ‘Abadamu’, ‘CIP-395109.34’ and ‘Gera’ also gave relatively better marketable yield at both seasons, the AMMI analysis showed that ‘Granola’, ‘Deme key’ (Key shall) and ‘Abadamu’ were more fitted to warm Belg season production while CIP-395109.34 better performed to the cool Mesino season. The AMMI analysis further showed that ‘Jalene’, ‘Rejim China’, ‘Siquare’, and ‘Sisay’ all had best fitted in the Mesino season, but all of these performed relatively poorly in the Belg season (Figure 2).

### *Genotypic variation in drought response*

Plant height, above ground biomass, and marketable and total tuber yield declined in stressed compared to well-irrigated treatments in almost all cases (Tables 3, 4), reflecting the sensitivity of the potato crop to drought (Wishart *et al.*, 2013; Lalouet *al.* 2003). However, yield potential and the magnitude of decline with stress varied among genotypes. The ‘Granola’, ‘CIP 395109.34’, ‘Gera’ and ‘Sisay’ improved varieties and ‘Abadamu’, ‘NechAbeba’ and ‘Rejim China’ local varieties were the highest yielding varieties in the Mesino season under both irrigated and stress conditions. However, these varieties did not outperform the widely grown local variety, ‘Siquare’ under stress conditions in the same season. In the Belg season, ‘Granola’ followed by ‘Abadamu’, ‘Gera’ and ‘CIP 395109.34’ had the highest marketable

tuber yields under both irrigated and stress conditions.

In the Belg season, 'Granola' gave 92.6% and 94.7% marketable tuber yield varieties in the Mesino season.

advantage over 'Siquare' in irrigated and stress conditions, respectively. All four of these varieties were also among the highest yielding

**Table 3:** Morphological characteristics of varieties tested in two watering regimes in two seasons

Variety	Mesino (cool) season								Belg (warm) season							
	PH		RL		SD		AGB		PH		RL		SD		AGB	
	I	S	I	S	I	S	I	S	I	S	I	S	I	S	I	S
Mean	60	55	43	47	34	36	26	22	56	47	37	41	41	45	33	27
Watering regimes	**		***		*		*		***		*		***		***	
Variety	***		***		***		*		***		**		***		***	
Watering regime*Var	NS		NS		*		*		*		NS		NS		NS	

Water regimes, I= well irrigated; S= stressed; PH= Plant height in cm; RL= Root length; SD= SPAD reading; AGB= Above ground biomass; MTY= Marketable tuber yield (g/plant); TTY= Total tuber yield; TTN = Total tuber number/plant (g/plant); HI= Harvest Index\* Significant at the *P* 0.05 level; \*\* Significant only at *P* 0.01 NS-non significant

AMMI biplot analysis also showed that most of the local varieties, even those that are low yielding, are close to the origin (Figure 2). 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 under water stress 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.

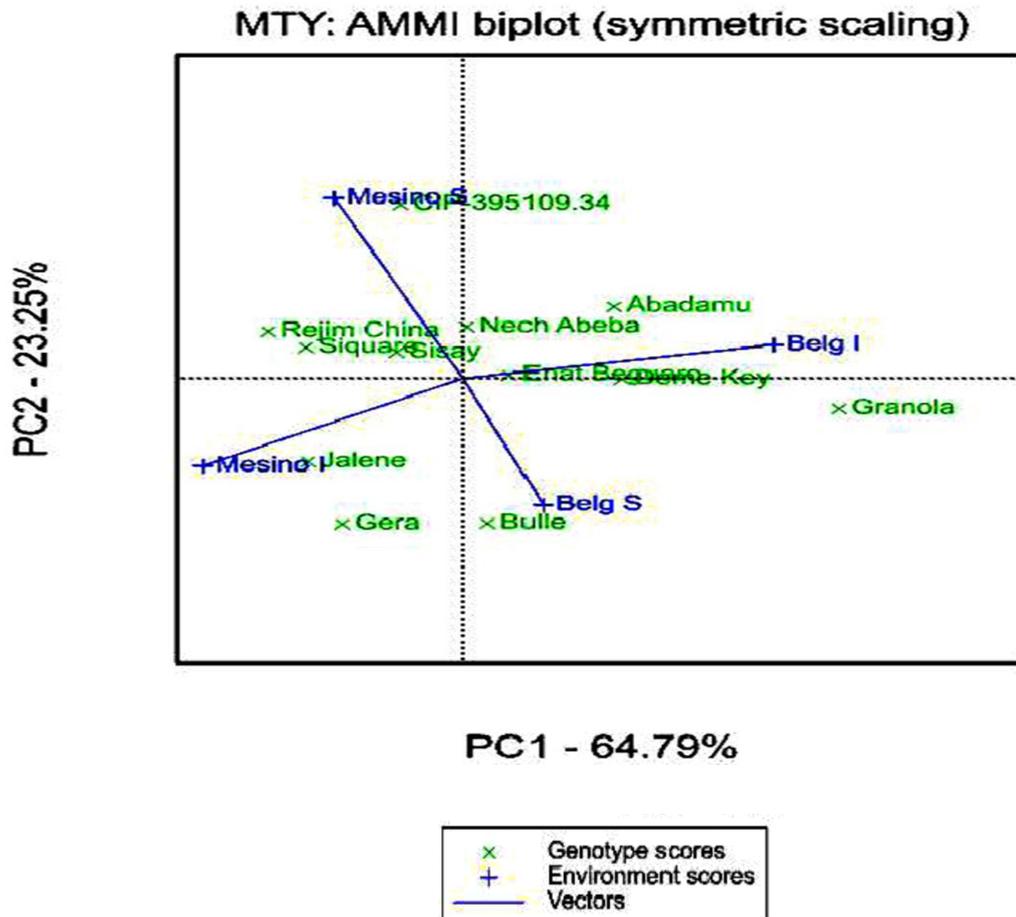


Figure 2: An AMMI (Additive Main Effects and Multiplicative Interaction) biplot reflecting the relationship of varieties and environment (seasons and water regimes). Mesino S= Mesino season with water stress treatment; Mesino I= Mesino season with well irrigated treatment; Belg S= Belg season with water stress treatment; Belg I= Belg season with well irrigated treatment.

Stress Susceptibility Index (SSI) is a good measure of varieties performance in drought stress. It does not take into account yield potential, but focuses on percent decline in performance due to stress relative

to other varieties in a trial. Improved varieties such as ‘Belete’, ‘CIP-395109-34’, ‘Granola’ and local varieties such as ‘Abadamu’ and ‘Agazer’ had the lowest SSI values in both marketable and total

tuber yields (indicating least susceptibility to stress) in the Mesino season (Figure 3). ‘Gera’, ‘Granola’, ‘Siquare’ and ‘Abadamu’ had the lowest values in the Belg season. These results are in agreement with previous work (Kolechet *et al.*, 2015) reporting that the local varieties such as ‘Abadamu’ and ‘Agazer’ had good tolerance to drought. ‘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 1 and Figure 3). 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 (Vos & Haverkort, 2007).

Harvest index (HI) differed between varieties, between seasons and between water regimes (Tables 2 and 4). However, it 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 & Haverkort, 2007). In contrast to the Mesino season, most varieties showed a decline of HI with stress in the Belg season,

with the exception of ‘EnatBeguaro’ and ‘Siquare’. Both of these local varieties did not well adapted to warm Belg season (Table 4). However, ‘Granola’ had the highest HI under both irrigated and stress conditions in this warmer Belg season (Table 4).

Drought stress can impact tuber quality and thus impact marketable yield more than total yield (Wolfe *et al.* 1983; Hassanpanah, 2010). Tuber size distribution is one of the factors most determining quality of potato during drought conditions (Mackerron & Jefferies, 1988). Accordingly, in the present study, the percent of small tubers increased in the stress compared to well-irrigated treatment in both seasons (Table 5), with the exception of varieties ‘Abateneh’, ‘CIP-395109.34’, and ‘EnatBeguaro’ in the Mesino season and ‘EnatBeguaro’ in the Belg season. Higher incidence of tuber deformation in both water regimes in the warmer season (Belg) and comparable percentage of small tubers in both water regimes in both seasons showed that ‘EnatBeguaro’ has a low yielding potential in these seasons. Tuber quality is also influenced by growth temperatures (Struik *et al.*, 1989) and growing season. 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 5). Deformed and green tubers were not found in any of the varieties in Mesino season.

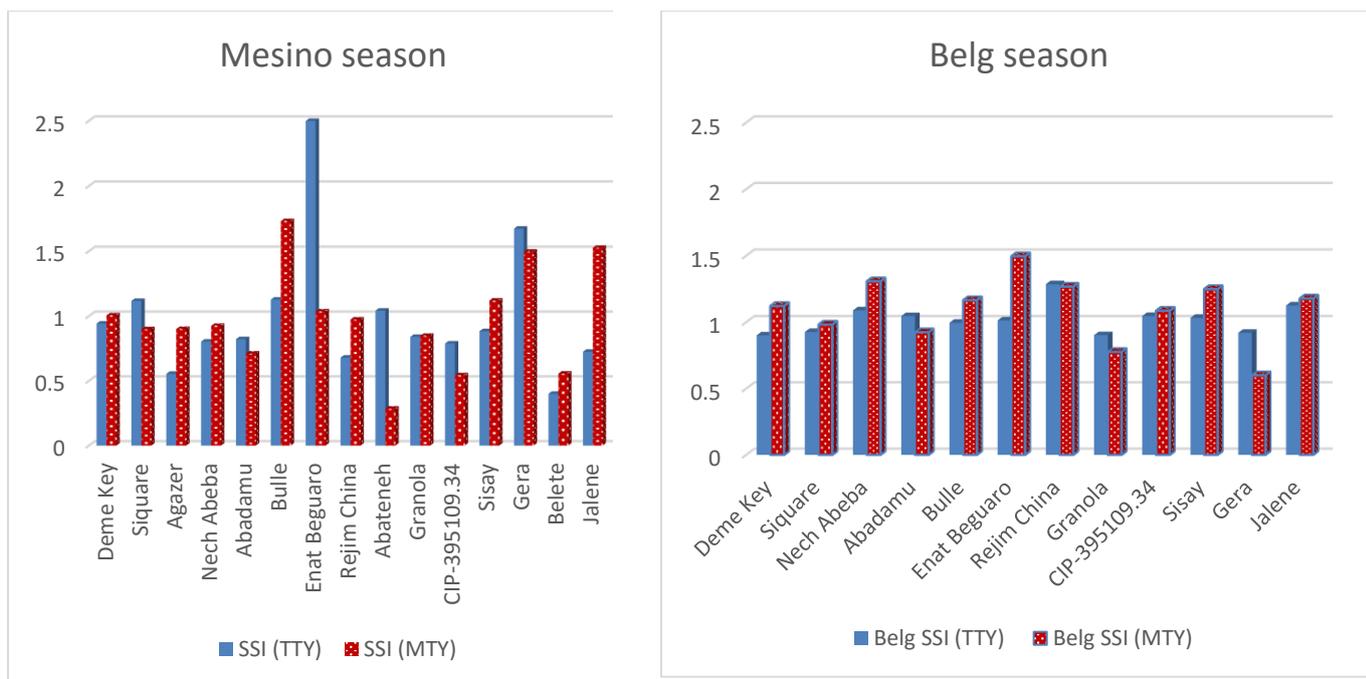
In contrast to the decrease in yield with stress, root length increased for many of the varieties under stress in both seasons (Figure 4). An increase in partitioning of

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 & Davis, 1990).

**Table 4:** Morphological characteristics of varieties tested in two watering regimes in two seasons

Variety	Mesino (cool) season								Belg (warm) season							
	PH		RL		SD		AGB		PH		RL		SD		AGB	
	I	S	I	S	I	S	I	S	I	S	I	S	I	S	I	S
Mean	60	55	43	47	34	36	26	22	56	47	37	41	41	45	33	27
Watering regimes	**		***		*		*		***		*		***		***	
Variety	***		***		***		*		***		**		***		***	
Watering regime*Var	NS		NS		*		*		*		NS		NS		NS	

Watering regimes, I= well irrigated; S= stressed; PH= Plant height in cm; RL= Root length; SD= SPAD reading; AGB= Above ground biomass; MTY= Marketable tuber yield (g/plant); TTY= Total tuber yield; TTN = Total tuber number/plant (g/plant); HI= Harvest Index\* Significant at the *P* 0.05 level; \*\* Significant only at p0.01 NS-non significant.



**Figure 3:** Water Stress Index for total tuber yield (TTY) and marketable tuber yield (MTY) of varieties tested for Mesino and Belg seasons

**Table 4:** Tuber yield and other tuber yield parameters of varieties under water stress and well irrigated conditions in two seasons

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
Deme Key (Key Shull)	480	343	569	452	0.8	0.8	216	54	503	296	0.5	0.6
Square	507	378	581	440	0.8	0.8	32 g	11	241	139	0.4	0.4
Agazer	411	306	581	511	0.8	0.8	-	-	-	-	-	-
NechAbeba	519	383	635	524	0.8	0.8	167	21	420	211	0.6	0.5
Abadamu	609	486	647	531	0.9	0.8	353	135	387	202	0.7	0.5
Bulle Local	466	238	612	462	0.9	0.8	77	17	367	200	0.6	0.4
EnatBeguaro	407 ef	287	609	277	0.9	0.8	44 g	0 d	421	226	0.5	0.5
Rejim China	563	408	668	569	0.8	0.8	59 fg	9 cd	342	141	0.5	0.3
Abateneh	263 f	241	392 e	303	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

Water regimes, I= well irrigated; S= stressed; 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

#### Yield determining traits for water stress tolerance

The correlation of several morphological and tuber yield components under water stress conditions combined over growing seasons were shown in Table 6. The correlation analysis found a positive and strong correlation ( $p<0.01$ ) between HI and marketable tuber yield under both stressed and well irrigated conditions ( $r = 0.8$  and  $0.85$ , respectively). This corroborates prior studies documenting the importance of maintaining HI as an adaptive trait for water stress conditions (Wolfe *et al.*, 1983; Lahlouet *et al.*, 2003). Total biomass was strongly and negatively correlated with HI

and marketable tuber yield in both stressed and well irrigated condition. This shows that high biomass can exacerbate water stress because of higher transpirational water loss in pot experiments.

Root length positively and strongly correlated with marketable tuber yield and harvest index in water stress condition but their correlation was weak in well irrigated condition. Similarly, we found that the average increase in root length under stress was more than 3 cm in both seasons (Table 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&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 (Figure 4), with ‘Bulle Local’, ‘Granola’, ‘Abadamu’, ‘Siquare’ and ‘Sisay’ having the greatest root response to water stress in the Mesino season, while ‘Granola’ and Demekey (Key Shull) had the most response in the Belg season. This result is inconsistent with the AMMI result that Granola and Deme Key (Key Shull) varieties are well adapted to Belg season condition.

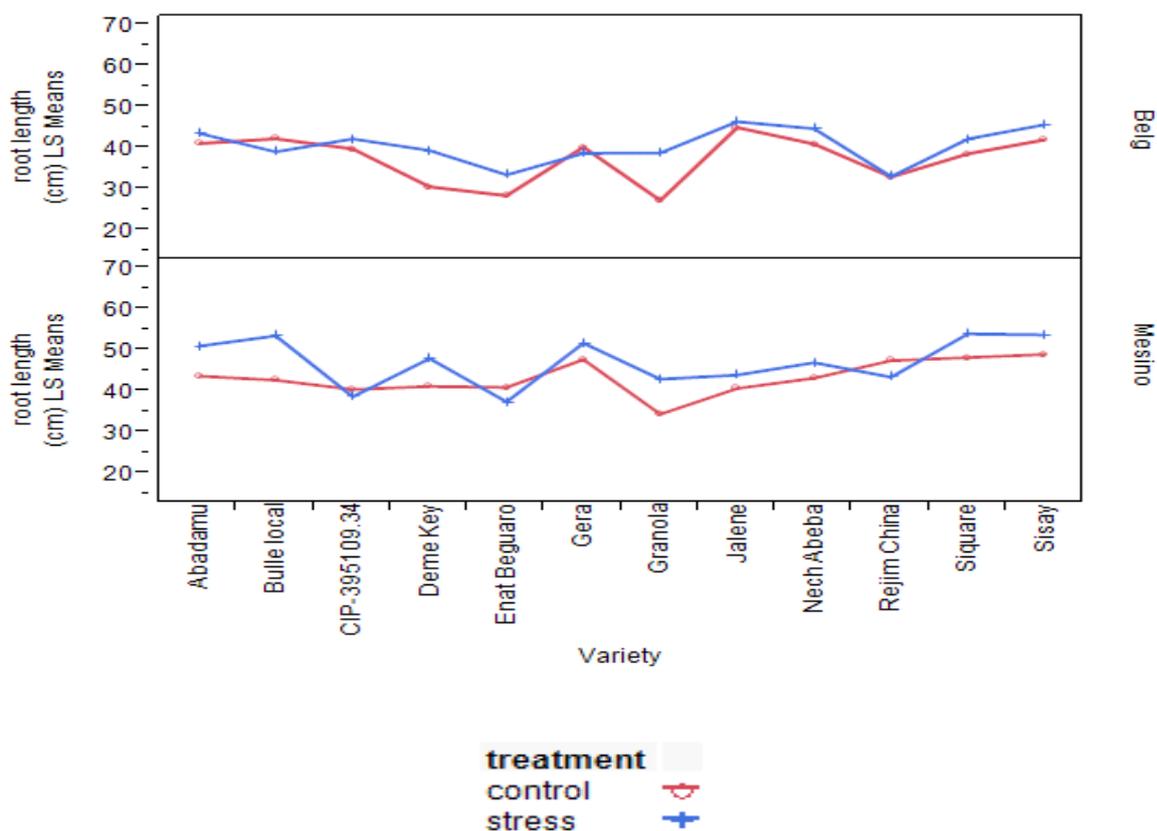
It is important to keep in mind that under field conditions with unreliable rainfall,

early maturing (i.e., short growing season) varieties may complete their life cycle and 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. The widely grown local varieties such as ‘Agazer’ and ‘Siquare’, 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 (Kolechet *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.

**Table 5:** Tuber quality of varieties under water stress and well irrigated conditions in two seasons

Variety	Mesino				Belg			
	% small tubers		% small tubers		% of deformed tubers (weight basis)		% of green tubers (weight basis)	
	Irrigated	Stressed	Irrigated	Stressed	Irrigated	Stressed	Irrigated	Stressed
Deme Key (Key Shull)	15.4	25.9	89.6	100	15	07	06	16
Siquare	12.9	14.1	48.5	84.2	00	02	29	11
Agazer	31.6	40.0	-	-	-	-	-	-
NechAbeba	22.9	26.8	83.4	93.3	00	04	04	18

Abadamu	5.5	8.3	79.4	92.9	06	11	16	40
Bulle	23.6	48.8	23.1	61.4	10	00	08	07
Local								
EnatBegua	33.4	30.7	45.5	45.2	29	09	09	08
ro								
Rejim	15.6	30.5	87.8	94.4	00	20	05	08
China								
Abateneh	38.8	23.0	-	-	-	-	-	-
Granola	8.1	14.9	58.8	80.8	03	00	01	01
CIP-	8.3	8.1	57.6	83.4	00	03	00	00
395109.34								
Sisay	2.3	18.3	8.6	34.0	13	13	08	05
Gera	5.1	13.1	18.9	33.3	04	07	00	00
Belete	18.5	21.3	-	-	-	-	-	-
Jalene	7.6	38.6	58.2	89.8	10	02	15	04
Mean	16.3	23.9	54.1	74.4	07	07	08	10



**Figure 4:** Root length in different watering regimes across different potato varieties and seasons (Mesino and Belg). LS represents least square while Control represents well irrigated treatment.

**Table 6:** Pairwise Correlation between tuber yield and other important traits, under stressed (above diagonal) and irrigated (below diagonal) conditions combined over cool and warm seasons

	RL	RSW	AGB	TTY	MTY	HI	SLW
RL	1	-0.19	-0.03	0.30**	0.34**	0.31**	-0.11
RSW	-0.10	1	0.49**	-0.49**	-0.51**	-0.61**	0.17
AGB	0.08	0.59**	1	-0.35**	-0.31**	-0.56**	0.52**
TTY	0.22*	-0.53**	-0.54**	1	0.92**	0.86**	-0.15
MTY	0.17	-0.58**	-0.54**	0.91**	1	0.80**	-0.11
HI	0.20	-0.65**	-0.70**	0.85**	0.85**	1	-0.23*
SLW	-0.02	0.07	0.33**	-0.17	-0.18	-0.15	1

RL= Root length; RSW= Roots and stolons dry weight per plant; AGB= above ground biomass (g); TTY= total tuber yield per plant (g); MTY= marketable tuber yield per plant (g); HI= harvest index; SLW= specific leaf weight; LAR= leaf area ratio. \*= Significant at  $P < 0.05$ ; \*\*= Significant at  $P < 0.01$

### Conclusion

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 percentage of small tubers 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. This 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 focused on identifying genotypic variation in marketable yield under water stress and quantifying plant traits associated with drought tolerance under controlled water management conditions. Several studies also found consistent results for many traits including root traits in pot and field experiments, but we recognize that this is not always the case and a next phase will be an evaluation of water stress responses under field conditions.

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