



# Morpho-Physiological Traits of Potato (*Solanum tuberosum* L.) for Post-Flowering Drought Resistance

Zerihun Kebede<sup>1</sup>, Firew Mekbib<sup>2</sup>, Tesfaye Abebe<sup>3</sup>, Asrat Asfaw<sup>4</sup>

10.18805/ag.D-191

## ABSTRACT

Though breeding for drought resistance is complicated due to the many processes involved and their interaction with the environment, availability of precise, cheap and easy to apply selection tool is critical. The present study quantified the response of potato genotypes to drought and identified potential morpho-physiological traits that are useful for selection of drought tolerant genotypes. The study assessed sixty genotypes under two irrigation regimes: fully watered non-stress and terminal drought, where the irrigation water supply to the crop was withheld after 50 % flowering to induce post-flowering stress. Measurements for various morpho-physiological, yield and quality related traits were taken following the potato crop trait ontology. The post-flowering stress induced in this study caused a tuber yield reduction of 33.13% compared with the non-stressed treatment. The genotypes responded differently in tuber yielding potential to the drought. This differential tuber yield response to drought was associated with up and downward regulation of multiple traits related to drought adaptation in potatoes. Drought caused downward regulation on trait responses such as harvest index, leaf area and specific leaf area. Plant height, aboveground biomass and relative water content of leaf contributed negatively for tuber yield under stressed condition. Therefore, the selection attributes identified from this study could help the potato breeding program in the country to develop climate resilient potato varieties.

**Key words:** Correlation, Drought resistance, Morpho-physiologic traits, Tuber yield.

## INTRODUCTION

The increasing awareness on its productive capability and food value placed potato among the world's important staple food crops. The potato tuber is known to supply carbohydrate, high quality protein and substantial amounts of essential vitamins, minerals and trace elements. Furthermore, there are evidences indicating that potatoes contain significant amounts of macronutrients, micronutrients and important antioxidants, including phenolic acids, flavonoids, ascorbic acid, carotenoids and tocopherols which are essential in the human diet (Gumul *et al.*, 2011). Such a crop undoubtedly has a promising prospect in improving the nutritional quality of human diets in Ethiopia, where inadequate supplies of protein and calories are the apparent problems.

In Ethiopia, potatoes are mostly cultivated in central, northwestern, southern and eastern parts of the country. Yet, in recent times, potato production has been increased substantially throughout the country from mid to high altitude areas and in lowlands to some extent both under rain-fed and irrigated conditions. Despite the efforts made the average productivity of potato at farmers' field is very low i.e 12.3 t ha<sup>-1</sup> and is about one-fourth of achievable yields (34-47 t ha<sup>-1</sup>) at research stations (MoA, 2015), which is about 83 and 61 % of the average African and global yields, respectively. Many diverse and complex biotic, abiotic and anthropogenic factors have contributed to the yield gap between the attainable potential yield and the existing low productivity of potato in Ethiopia.

Among the abiotic stresses, drought is the most complex and serious danger to global agricultural production (Pennisi, 2008). Potato regularly suffers a transient water deficit in most of the rain-fed growing regions due to erratic rainfall or inadequate supplemental irrigation techniques

<sup>1</sup>Amhara Regional Agricultural Research Institute, Debre birhan Agricultural Research Center, Debre birhan, Ethiopia.

<sup>2</sup>Haramaya University, Haramaya, Ethiopi.

<sup>3</sup>Ethiopian Institute of Agricultural Research, Holeta Agricultural Research Center, Holeta, Ethiopia.

<sup>4</sup>International Institute of Tropical Agriculture, Oyo state, Nigeria.

**Corresponding Author:** Zerihun Kebede, Amhara Regional Agricultural Research Institute, Debre birhan Agricultural Research Center, Debre birhan, Ethiopia. Email: zublinortho@gmail.com

**How to cite this article:** Kebede, Z., Mekbib, F., Abebe, T. and Asfaw, A. (2020). Morpho-Physiological Traits of Potato (*Solanum tuberosum* L.) for Post-Flowering Drought Resistance. Agricultural Science Digest. 40(1): 19-26.

**Submitted:** 24-08-2019 **Accepted:** 11-01-2020 **Published:** 06-03-2020

(Thiele, 2010). Cut-off rain late in the growing season is the main cause for potatoes to suffer from drought in the 'Belg' (February to May) and 'Belmehr' (March to August) season production practices in the major production ecologies in Ethiopia (Semagn *et al.*, 2015). Moreover, drought tolerance is amongst the priority traits growers make choice for cultivars to plant. The search for and development of drought tolerant varieties are of utmost urgency. Therefore, this particular study was carried to evaluate the response of potato genotypes for post flowering drought stress and identify morpho-physiological traits en route for identifying drought resistant genotypes.

## MATERIALS AND METHODS

### Description of the study area

The study was conducted under irrigated condition in 2015/16

**Table 1:** Metrological description of the study area during the cropping months.

Parameters	January	February	March	April	Mean
Minimum temperature (°C)	7.40	8.73	10.44	12.17	9.69
Maximum temperature (°C)	28.60	31.32	30.89	30.56	30.34
Mean Rain fall (mm)	3.43	4.88	15.13	44.51	16.99
Relative humidity (%)	48.19	44.25	42.06	42.35	44.21
Sunshine hours (hr.)	9.51	8.99	8.78	8.73	9.00

at Koga trial site of Adet Agricultural Research Center located in Amhara National Regional State, Ethiopia. It has got an elevation of 1960 meter above sea level. Its soil represents a heavy clay-textured red Nitrosol. A detail of climatological and geographic descriptions of the study area are indicated below in Table 1 and Fig 1.

### Experimental materials

The experiment was conducted using a total of 60 potato clones of which 52 are introduced from CIP (*Centro Internacional de la Papa*), Lima, Peru, six are released varieties in Ethiopia, one introduced variety and one is a local check cultivar (Table 2).

### Experimental design and management

The experiment was laid out in a 10 x 6 alpha lattice design with two replications and under two moisture regimes (stressed and non-stressed). Well-sprouted seed tubers were planted at a spacing of 75cm between rows and 30 cm between plants on a plot. All other standard agronomic operations such as earthing-up, weeding and fertilization were uniformly carried-out over entire experimental plot irrespective of water regime.

Under non-stressed treatment, genotypes were regularly watered using surface furrow irrigation at a week interval until physiological maturity, while in the stressed treatment; the genotypes were regularly irrigated at a week interval till 50 % of the genotypes initiated flowering and then totally cut-off irrigation water supply till the end of maturity starting from 50% flowering stage of each treatment. The non-stress trial received 6-8 times irrigations between flowering and physiological maturity to ensure optimum crop growth. The stress plots were covered with a movable rain out shelter when the rain seems to shower.

### Soil moisture

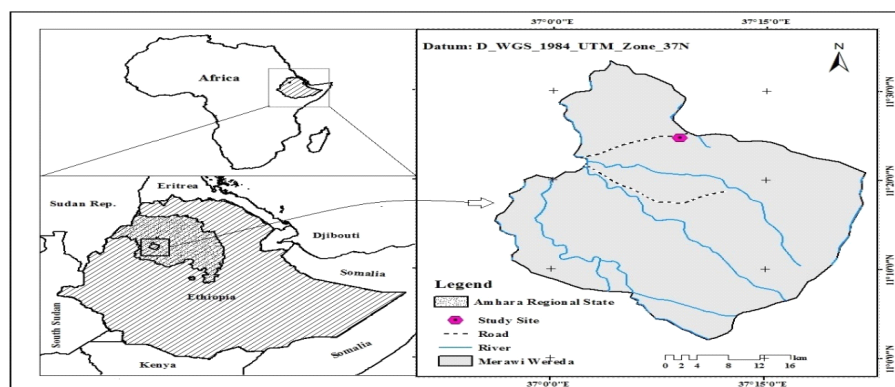
Soil moisture during the plant growth period was recorded by installing a Watermark Meter (Model 2000ss, IRROMETER Company, INC, USA) on 12 representative points across the stress and non-stress fields. Measurements were taken at a soil depth of 15, 30 and 45cm during various growth stages *i.e.* at full emergence, 50 % flowering, 15 days from the onset of the stress, 30 days from onset of the stress and at physiological maturity.

### Evaluation of morphological, physiological, yield and quality traits

Data on growth, performance and quality traits of potato *i.e.* days to flowering, days to physiological maturity, plant height, stem number per plant, leaf area, specific leaf area, excised leaf water loss, relative water content of leaf, above ground biomass per plant, harvest index, average tuber weight per plant, size distribution of the tubers, percent dry matter content and specific gravity of tubers were collected. Moreover, excised leaf water loss, relative water content of leaf, harvest index and percentage dry matter content of tubers were calculated following the below scribed standard evaluation protocols.

$$\text{Excised leaf water loss (ELWL)} = \frac{\text{ELW} - 2\text{HDLW}}{\text{DLW}}$$

Where, FLW= fresh leaf weight, 2HDLW= two hours dry leaf weight and DLW= dry leaf weight. The procedures were as follows, six fully expanded leaves were randomly sampled from each plots after 20 days of imposing the stress. The fresh weight was measured immediately and the leaves left to wilt for two hours under room temperature and then

**Fig 1:** Map of the study area.

**Table 2:** List of potato genotypes used in the study.

Genotype ID	Code	Genotype ID	Code	Genotype ID	Code
Guassa	1	CIP-381379.12	21	CIP-396004.225	41
CIP-304345.47	2	CIP-310135.14	22	CIP-398190.735	42
CIP-396038.101	3	CIP-395077.12	23	CIP-398193.65	43
Belete	4	CIP-301024.14	24	Granola	44
CIP-393077.54	5	CIP-301040.63	25	CIP-397054.3	45
CIP-391045.74	6	CIP-301024.95	26	CIP-396036.201	46
CIP-304356.32	7	Jallene	27	CIP-399048.24	47
CIP-395169.17	8	CIP-302498.7	28	CIP-399001.44	48
CIP-398089.119	9	CIP-396037.215	29	Gudene	49
CIP-396285.1	10	CIP-398192.41	30	CIP-397014.2	50
CIP-391533.1	11	CIP-398208.29	31	CIP-300054.29	51
CIP-392639.34	12	CIP-398190.53	32	CIP-395015.6	52
CIP-398190.605	13	CIP-397029.21	33	CIP-391580.3	53
CIP-380011.12	14	CIP-391011.17	34	CIP-399085.17	54
CIP-393227.66	15	CIP-396272.21	35	CIP-300099.22	55
CIP-301044.36	16	CIP-384866.5	36	CIP-304371.67	56
CIP-398180.612	17	CIP-398208.704	37	CIP-302499.3	57
CIP-397069.5	18	Gorebella	38	CIP-396272.37	58
CIP-396046.105	19	CIP-396027.205	39	Shenkolla	59
CIP-394898.13	20	CIP-391065.69	40	Ater abeba	60

weighed. The leaves were then oven dried at 80°C for twenty four hours and the dried weight was measured.

$$\text{Relative water content of leaf (RWC)} = \frac{\text{FW} - \text{DW}}{\text{TW} - \text{DW}} \times 100$$

Where, FW=fresh leaf weight, DW=dry leaf weight and TW=weight at full turgor. DW was determined by oven drying of leaves at 80°C for 24 h and TW was determined from plants that have been watered and kept overnight in petridishes.

$$\text{Harvest Index (HI)} = \frac{\text{EY}}{\text{TB}} \times 100$$

Where, EY=economic yield and TB= total biomass

$$\text{Percent dry matter content (DM)} = \frac{\text{WF}}{\text{WO}} \times 100$$

Where,  $W_f$  = weight of sample after drying (g);

$W_o$  = initial weight of sample (g)

### Data analysis

**a. Analysis of variance:** Morpho-physiological, yield and quality related data were analyzed using the following linear model in alpha lattice design using SAS 9.1 statistical software and mean comparisons were done using Duncan Multiple Range Test.

$$Y_{ijk} = \mu + t_i + r_j + B_{k(j)} + E_{ijk}$$

Where,  $Y_{ijk}$  denotes the value of the observed trait for  $i^{\text{th}}$  treatment received in the  $k^{\text{th}}$  block within  $j^{\text{th}}$  replicate (superblock),  $t_i$  denotes the fixed effect of the  $i^{\text{th}}$  treatment ( $i = 1, 2, \dots, t$ );  $r_j$  denotes effect of the  $j^{\text{th}}$  replicate (superblock) ( $j = 1, 2, \dots, r$ );  $B_{k(j)}$  denotes effect of the  $k^{\text{th}}$  incomplete block

within the  $j^{\text{th}}$  replicate ( $k = 1, 2, \dots, s$ ) and  $e_{ijk}$  denotes experimental error associated with the observation of the  $i^{\text{th}}$  treatment in the  $k^{\text{th}}$  incomplete block within the  $j^{\text{th}}$  complete replicate.

### b. Estimation of phenotypic and genotypic correlation coefficients:

The phenotypic and genotypic correlation coefficients were calculated to find out the relationships of tuber yield and other traits using Multivariate Restricted Maximum likelihood (REML) with Proc MIXED of the SAS system v.9.1 statistical software.

$$\text{Phenotypic correlation coefficients (Pr)} = \frac{\text{Cov}_{p12}}{\sqrt{(\sigma^2 p_1) \times (\sigma^2 p_2)}}$$

Where,  $\text{Cov}_{p12}$  is the phenotypic covariance of the progeny means between the two traits and  $\sigma^2 p_1$  and  $\sigma^2 p_2$  are the phenotypic variance for each trait.

$$\text{Genotypic correlation coefficients (Gr)} = \frac{\text{Cov}_{g12}}{\sqrt{(\sigma^2 g_1) \times (\sigma^2 g_2)}}$$

Where,  $\text{Cov}_{g12}$  is the genotypic covariance between two traits,  $\sigma^2 g_1$  is the genotypic variance of the first trait and  $\sigma^2 g_2$  is the genotypic variance of the second trait.

The coefficients of correlations at phenotypic level were tested for their significance by comparing the value of correlation coefficient with tabulated  $r$ -value at  $g-2$  degree of freedom. However, the coefficients of correlations at genotypic level were tested for their significance using the formula indicated below.

$$t = \left( \frac{rg_{12}}{\text{SE}g_{12}} \right)$$

Where,  $rg_{12}$  = genotypic correlation coefficient and  $\text{SE}g_{12}$

= standard error of genotypic correlation coefficient between character 1 and 2.

$$SEg_{12} = \sqrt{\frac{(1 - r^2 g_{12})}{2 H^2_1 \cdot H^2_2}}$$

Where,  $H^2_1$  = Heritability value of character 1; and  $H^2_2$  = Heritability value of character 2. The calculated absolute 't' value was compared with the tabulated 't' value at g-2 degree of freedom at 5 and 1% level of significance for both phenotypic and genotypic correlations, where, g = number of genotypes.

## RESULTS AND DISCUSSION

### Soil moisture conditions

The soil water content was considerably reduced from flowering onward until physiological maturity in the stress trial (Fig 2). The intensity of drought increased with increase in time from which the stress was induced and is verified in terms of increment of tension force on the plant root to suck water. Variation in moisture content was recorded at different soil depths both under stress and non-stress conditions.

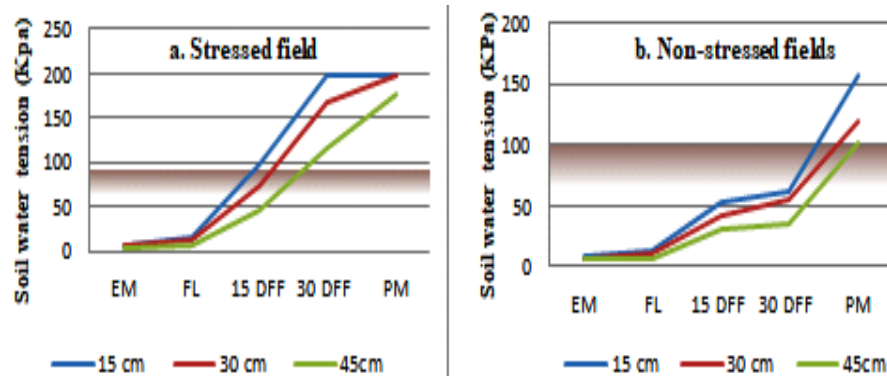


Fig 2: Soil moisture status of the stressed and non-stressed experimental sites.

Table 3: ANOVA of morpho-physiological, yield and quality related traits of potato genotypes, 2016.

Sources	Stressed field																
	DPM	PH	AGB	HI	LA	SLA	ELWL	RWC	LAR	MED	SM	MARK	TOT	YPP	TNP	SG	DMC
Group	ns	ns	ns	ns	**	**	*	ns	ns	ns	*	ns	ns	ns	ns	ns	ns
Block(Group)	ns	ns	ns	*	*	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns
Entry	**	**	ns	**	**	*	**	*	**	**	*	*	*	*	**	**	**
CV (%)	4.2	8.6	28.7	12.4	19.6	19.6	31.6	9.4	26.7	11.6	29.8	26.0	25.7	25.8	20.1	0.7	7.2
Sources	Non-stressed field																
		PH	AGB	HI	LA	SLA	ELWL	RWC	LAR	MED	SM	MARK	TOT	YPP	TNP	SG	DMC
Group	ns	**	**	ns	*	ns	**	ns	*	*	ns	*	*	*	ns	*	*
Block(Group)	ns	ns	*	*	ns	ns	ns	ns	*	*	*	*	ns	ns	ns	ns	ns
Entry	**	**	**	**	**	*	*	ns	**	**	**	*	*	*	**	*	**
CV (%)	3.9	7.5	21.8	6.0	18.0	15.8	32.2	8.0	16.4	13.2	19.6	16.3	16.2	3.1	19.5	0.7	7.5

CV: coefficient of variation; DPM: days to physiological maturity, PH: plant height, AGB: above ground biomass, HI: harvest index, LA: leaf area, SLA, Specific leaf area, ELWL: excised leaf water loss, RWC: relative water content of the leaf LAR: % of large size tubers, MED: % of medium size tubers, SM: % of small size tubers, MARK: marketable tuber yield, TOT: total tuber yield, YPP: yield per plant, TNP: tuber number per plant, SG, specific gravity and DMC: dry matter content.

\* and \*\* represent significant differences at the 0.05 and 0.01 levels, respectively.

days earlier than those in non-stressed conditions which designate as early maturity is the key response of potato expressed to mitigate the effect of drought. This was in agreement with the findings of Kumar *et al.* (2007) and Yucel (2018) who reported as drought affects potato crop by shortening the growth cycle. Earliness is related to drought escape; hence early maturing genotypes reduce yield loss thereby shortening the period that they are exposed to the stress. However, early maturity is often associated with lower yield potential under non-stress or mild stress conditions, compared with late maturing varieties, due to a shorter growth period (Levy *et al.*, 2006). Late maturing potatoes usually yield more than early maturing ones because they have more time to produce photoassimilate and partition it to the tubers (Kleinkopf *et al.*, 1987).

#### b. Plant height

Plant height ranged from 24.64-73.3 cm in non-stressed and from 22.25-66.4 cm in the stress treatment. Deblonde and Ledent (2001) reported that plant height of potato was sensitive to drought and the effect was stronger on late cultivars especially when water shortage started early. Moreover, Kirnak *et al.* (2001) suggested as severe water stress reduced plant height by 46 % in a pot experiment. However, in the current study, drought caused insignificant plant height reduction due to the post flowering nature of the stress treatment where plants mostly attained the optimum plant growth before the stress induction period.

#### c. Above ground biomass

Compared to the non-stressed environment above ground biomass was declined by 6.3 % under stress environment. The ability of potato to form a large above ground biomass is an effective insurance against soil water deficit (Schittenhelm *et al.*, 2006). Biomass reduction of potato crops in response to drought is in agreement with a study by Saravia *et al.* (2016) who reported as drought significantly reduced the total biomass of potato. A small above ground dry weight is considered to be associated with poor drought resistance in potato (Deguchi *et al.*, 2010). However, large above ground biomass could raise the rate of water loss through transpiration. Schittenhelm *et al.* (2006) reported

that a cultivar with a compact canopy easily showed a reduced radiation interception even with a small reduction of shoot dry weight. Hence, a genotype with minimum above ground biomass and however, compact canopy could able to tolerate drought through minimizing evaporative losses and increasing photosynthetic efficiency.

#### d. Harvest index

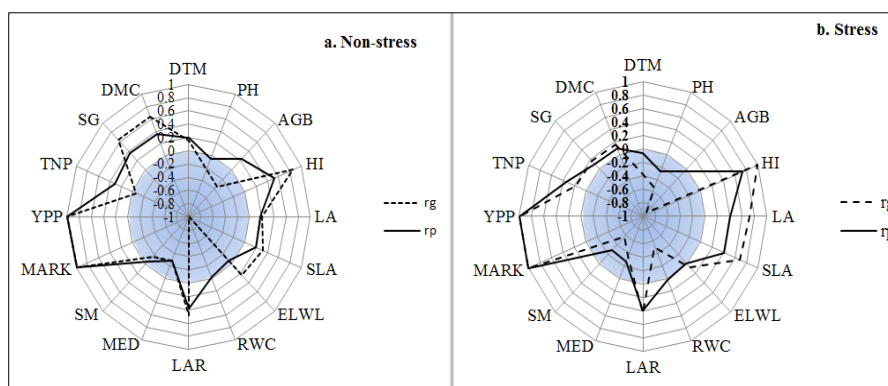
Harvest index shows the extent of remobilization of photosynthates to tubers. Identifying genotypes that use photosynthates for greater tuber expansion at the expense of shoot biomass will help in drought resistance selection. Deblonde and Ledent (2000) suggested that moderate drought conditions did not influence the harvest index. However, our finding revealed that drought caused a reduction in harvest index by 10.34 % compared to the non-stressed environment which is in agreement with the finding of Rana and Chaudhary (2013). The extent of differences in harvest index is dependent on potato cultivars tested in stressed condition (Lahlou *et al.*, 2003). Maintaining a high harvest index in drought prone environments may contribute to achieve high and stable potato yields (Deguchi *et al.*, 2010).

#### Response of leaf and water relation parameters for drought stress

In both stressed and non-stressed environments, Table 3 presents the presence of significant ( $p \leq 0.05$ ) difference was observed between genotypes in all leaf and water relation traits such as leaf area, specific leaf area and excised leaf water loss. In terms of the leaf relative water content, significant ( $p \leq 0.05$ ) difference between potato genotypes was observed only under stressed environment. The detail genotypic variations of these traits were discussed below.

#### a. Leaf area and specific leaf area

Leaf area ranged from 58.63 - 179.42 cm<sup>2</sup> and from 53.05 - 174.39 cm<sup>2</sup> under non stress and stressed environments, with mean leaf area of 90.26 cm<sup>2</sup> for non-stressed and 95.70 cm<sup>2</sup> for stressed treatments, respectively. Drought results in decreased leaf expansion, inhibits the development of new leaves and encourages senescence (Fleisher *et al.*,



**Fig 3:** Phenotypic and genotypic correlations of different traits with tuber yield.  
NB: Shaded area at the center represents negative correlation.



2008). However, the minimal variation in leaf area among stressed and non-stressed treatments might be due to lower expansion rate of leaf at flowering and then after.

Anyia and Herzog (2004) reported as specific leaf area is amongst the traits to serve as index for drought resistance. In our experimentation, specific leaf area ranged from 6.74 - 17.0 cm<sup>2</sup>/g under non stress environments whereas it was 6.2 - 18.9 cm<sup>2</sup>/g under stressed environment. A reduction in specific leaf area is generally observed for grain legumes under water stress (Muchow, 1985); possibly indicating thicker leaves which aids in leaf water conservation because of the low surface/volume ratio. Specific leaf area was reduced by 2.2 % under non-stress condition compared to the stress treatment. Ashinie *et al.* (2011) also reported as the specific leaf area of Ethiopia durum wheat genotypes was increased by 12.6% under water deficit relative to the non-stressed treatment.

#### **b. Excised leaf water loss**

Excised leaf water loss estimates leaf transpiration rate by measuring the proportion of water loss through leaf cuticles and could be used for screening genotypes for drought resistance. It has shown a promising prospect in characterizing drought resistance in wheat (Mir *et al.*, 2012). It has ranged from 0.69-2.02 under non-stressed and from 0.4-2.74 under stressed environment. Compared to the non-stressed treatment, excised leaf water loss has a 10.68% reduction under stressed environment.

#### **c. The leaf relative water content**

Relative water content indicates the balance between water supply to the leaf tissue and transpiration rate, reflecting the metabolic activity in the tissues and used as a most meaningful index for dehydration resistance (Rana and Chaudhary, 2013). Drought significantly influenced and caused an average leaf relative water content reduction of 10.7 % under stress compared to the non-stress. Maralian *et al.* (2014) and Mensah *et al.* (2006) reported with decreasing irrigation, relative water content decreased from 82.4 - 69.7 % in potatoes and from 79.8 - 66.5% in sesame, respectively. Thought it was cultivar dependent, the leaf relative water content of potato declined markedly under stressed condition (Shi *et al.*, 2015). Relative water content of the genotypes ranged from 56-76% under stress treatment and from 74-96% under non-stress environments in the current study. Schonfeld *et al.* (1988) observed a decline in the amount of relative water content in wheat due to drought and reported the highest relative water content in the tolerant genotype.

#### **Response of tuber yield and quality traits for drought stress**

Significant ( $p \leq 0.05$ ) difference was observed between genotypes in all parameters of size distribution of tubers, yield and quality related traits of potato in both stressed and non-stressed environments (Table 3). The detailed genotypic variations of these traits were discussed below.

#### **a. Tubers size grade distribution**

The larger size tubers percentage ranged from 1.74-7.84% in non-stressed and from 0.7-6.5 % in stress treatment with a mean of 5.59 and 4.17%, respectively. Medium size tubers ranged from 37.2-92.4% in non-stressed and from 53.77-97.03% in stress environment with a mean of 62.23 and 74.47%, respectively. Smaller tubers ranged from 0.76-2.8% in non-stressed and from 0.8-4.07% in stress environment with a mean of 1.41 and 1.67%, respectively. Drought stress had a statistically significant influence on size distribution of potato tubers. The percentages of medium and smaller tubers were by 19.66 and 18.7% higher under stress environment than the non-stressed condition. Gregory and Simmonds (1992) reported a decline of 25.31% of larger size tubers with exposure to drought. Mahmud (2014) also reported a small proportion of smaller and medium sized tubers compared to the larger sized tuber under non-stress condition and the vice versa under drought conditions. The same author articulated as water deficit during tuber formation stage is a contributing factor for the decrease in number and size of potato tubers under drought condition.

#### **b. Tuber number and weight**

Drought caused about 33% marketable and total tuber yield reduction compared to the non-stress. Luitel *et al.* (2015) reported a 78.4% reduction on marketable tuber yield due to the post-emergence stress as compared to irrigated treatment. Similarly, Shi *et al.* (2015) reported 37-64% tuber yield reduction in potato cultivars exposed to stress compared with the non-stressed. Total tuber yield ranged from 12.34 to 45.1 tha<sup>-1</sup> under non-stress with mean of 31.9 tha<sup>-1</sup>. Under stressed condition, total tuber yield ranged from 8.9 to 31.94 tha<sup>-1</sup> with mean of 21.35 tha<sup>-1</sup>. Yield per plant ranged from 0.3-1.02 kg under non-stress and from 0.2-0.71 kg under stress treatment with mean tuber yield per plant of 0.72 and 0.48 kg, respectively. Drought reduced the number of total tuber number per plant by 10.23% on potato genotypes considered for this study. Similarly, Luitel *et al.* (2015) reported the total tuber number decrease of 7% under drought compared to the non-stressed treatment.

#### **c. Quality attributes**

Specific gravity ranged from 1.05-1.115 gcm<sup>-3</sup> and from 1.06-1.114 gcm<sup>-3</sup> under non-stressed and stressed treatments, respectively. Dry matter content ranged from 13.9-28.5% under non-stress and from 17.65-28.2% under stressed treatment. Tubers from water stressed plants often have higher contents of total sugars and dry matter than the non-stressed plants (Levy, 1983). Similarly, we have found that drought generally increased both specific gravity (0.36%) and dry matter content (4%) of tubers. This result is in agreement with the finding of Iahlou *et al.* (2003) who reported 2.5-10% increase of tuber dry matter concentration of potatoes due to drought. Eldredge *et al.* (1996) also observed an increase in specific gravity in Russet Burbank cultivar under deficit irrigation in sandy soil.

### Correlation of morpho-physiological traits with tuber yield of Potato

Increased tuber yield with consumer acceptable quality is the main objective of any potato breeding program. Better understanding of the relationship of various traits that affect the growth, productivity and quality of the potato crop is of greater importance in variety development as selection for one trait might cause an increase or deterioration on the other trait. The choice of trait as drought resistance selection criteria depends on its degree of association with improved yield under drought condition, simplicity to measure and heritability.

The results of the correlation study (Fig 3) revealed that phenotypic and genotypic relationship between tuber yield and its contributing characters exist in potatoes under both moisture regimes. In majority of the cases, the genotypic correlation coefficients were higher than the corresponding phenotypic correlation coefficients. The lower phenotypic correlation could be attributed to the environmental modification on the expression of the phenotypic correlations between traits. Johnson *et al.* (1955) also reported that the higher genotypic correlation than phenotypic correlation indicated an inherent association between various characters of soya bean.

Improvement of tuber yield in potato is possible by using appropriate breeding strategy through selecting for those traits which are positively associated with yield per plant. In this view, under stressed environment, total tuber yield had a significant and positive genotypic correlation coefficients with harvest index ( $r=0.996$ ), leaf area ( $r=0.71$ ), specific leaf area ( $r=0.69$ ), marketable tuber yield ( $r=0.997$ ) and tuber yield per plant ( $r=0.99$ ). Maintaining a high harvest index, leaf area and specific leaf area under drought prone environments, therefore, may significantly contribute to realize a high and stable potato yields which is in accordance with Deguchi *et al.* (2010) and Muchow (1985).

On the contrary, the total tuber yield had a significant and negative association with plant height ( $r=-0.54$ ), above ground biomass ( $r=-0.92$ ), relative water content of leaf ( $r=-0.51$ ) and percentage of smaller size tubers ( $r=-0.58$ ). Retaining a high plant height, above ground biomass and relative water content and percentage of smaller sized tubers under drought prone environments might significantly contribute to identify potato genotypes which are susceptible for drought.

The pattern of stomatal response under stress condition is an important factor in determining the sensitivity of a plant to water stress. Some plant species close their stomates to reduce water loss, while others leave their stomata open allowing photosynthesis to continue. This signifies that photosynthetic activities were continued even under stress condition with the expense of water loss from leaves. Turner (1974) suggested that the greater yielding ability of sorghum than maize under conditions of water stress resulted from the ability of sorghum to maintain stomatal aperture at lower water content. However, Schonfeld *et al.* (1988) reported

the highest relative water content in the drought tolerant genotypes of wheat.

The pattern of trait correlation under non-stress was positive and strong between total tuber yield and harvest index ( $r=0.85$ ), marketable yield ( $r=0.99$ ), specific gravity ( $r=0.64$ ) and tuber dry matter content ( $r=0.64$ ). The positive association of tuber yield with harvest index is in agreement with the finding of Fekadu *et al.* (2013).

### CONCLUSION

Water stress significantly influenced the expression of various morpho-physiologic traits and adversely affected tuber yield and quality attributes of the genotypes. The potato genotypes showed variable sensitivity to drought. The differential response of genotypes could be related to the genetic architectural differences among genotypes and their effect on some morpho-physiologic traits responses. Though the intensity of stress was considered as mild, post flowering drought caused a reduction of 33.13% total tuber yield as compared to the non-stressed condition. The correlation analysis revealed the presence of phenotypic and genotypic associations between tuber yield and other traits which can potentially be employed for selection in breeding strategies. Under stress treatment, harvest index, leaf area and specific leaf area exhibited positive association with tuber yield, whereas plant height, above ground biomass and relative water content showed negative correlation with tuber yield. The traits which exhibited a higher correlation with yield of potato under stress condition could be used as a selection tool for future breeding works on drought resistance.

### REFERENCES

- Anyia, A.O. and Herzog, H. (2004). Water-use efficiency, leaf area and leaf gas exchange of cowpeas under mid-season drought. *European Journal of Agronomy*. 20: 327-339.
- Asredie, S., Donald, H., Walter, D.J., Keith, P., David, W., Fentahun Mengstu and Schuiz, S. (2015). Potato variety diversity, determinants and implications for potato breeding strategy in Ethiopia. *American Journal of Potato Research*. 92:551-566.
- Bogale, A., Tesfaye, K. and Geleto T. (2011). Morphological and physiological attributes associated to drought resistance of Ethiopian durum wheat genotypes under water deficit condition. *Journal of Biodiversity and Environmental Sciences*. 1:22-36.
- Deblonde, P.M.K. and Ledent, J.F. (2001). Effects of moderate drought conditions on green leaf number, stem height, leaf length and tuber yield of potato cultivars. *European Journal of Agronomy*. 14: 31-41.
- Deguchi, T., Naya, T., Wangchuk, P., Itoh, E., Matsumoto, M., Zheng, X., Gopal, J. and Iwama, K. (2010). Aboveground characteristics, yield potential and drought resistance in Konyu potato cultivars with large root mass. *Potato Research*. 53: 331-340.
- Eldredge, E.P., Holmes, Z.A., Mosley, A.R., Shock, C. C. and Stieber, T. D. (1996). Effects of transitory water stress on potato tuber stem-end reducing sugar and fry color. *American Potato Journal*. 73: 517 -530.

- Fekadu, A. Petros, Y. and Zeleke, H. (2013). Genetic variability and association between agronomic characters in some potato (*Solanum tuberosum* L.) genotypes in SNNPRS, Ethiopia. *International Journal of Biodiversity and Conservation*. 5: 523-528.
- Fleisher, D.H., Timlin, D.J. and Reddy, V.R. (2008). Interactive effects of carbon dioxide and water stress on potato canopy growth and development. *Agronomy Journal*. 100: 711-719.
- Gregory, P.J. and Simmonds, L.P. (1992). Water relations and growth of potatoes. pp. 214-246. In: *The Potato Crop: The Scientific Basis for Improvement*, 2<sup>nd</sup> ed, [Harris, P.M. (Ed.)], Chapman and Hall, London.
- Gumul, D., Ziobro, R., Noga, M. and Sabat, R. (2011). Characterization of five potato cultivars according to their nutritional and pro-health components. *Acta Scientiarum Polonorum, Technologia Alimentaria*. 10: 73-81.
- Johnson, H. W., Robinson, H. F. and Comstock, R. E. (1955). Estimation of genetic and environmental variability in soyabean. *Agronomy Journal*. 47: 314-318.
- Kumar, S., Asrey, R. and Mandal, G. (2007). Effect of differential irrigation regimes on potato (*Solanum tuberosum*) yield and post-harvest attributes. *Indian Journal of Agricultural Science*. 77: 366-368.
- Kirnak, H., Kaya, C., Tas, I. and Higgs, D. (2001). The influence of water deficit on vegetative growth, physiology, fruit yield and quality in eggplants. *Bulgarian Journal of Plant Physiology*. 27: 34-46.
- Kleinkopf, G.E., Westermann, D.T., Wille, M.J. and Kleinschmidt, G.D. (1987). Specific gravity of Russet Burbank potatoes. *American Potato Journal*. 64: 579- 587.
- Lahlou, O., Ouattar, S. and Ledent, J.F. (2003). The effect of drought and cultivar on growth parameters, yield and yield components of potato. *Agronomie, EDP Sciences*. 23: 257-268.
- Levy, D. (1983). Varietal differences in the response of potatoes to repeated short periods of water stress in hot climates. *Potato Research*. 26: 315-321.
- Levy, D., Fogelman, E., Itzhak, Y., Ma, Q., Turner, D.W. and Cowling W.A. (2006). Osmotic adjustment in leaves of Brassica oil seeds in response to water deficit. *Canadian Journal of Plant Science*. 86: 389-397.
- Luitel, B.P., Khatri, B.B., Choudhary, D., Paudel, B.P., Sung Jung-Sook, S.J., Hur, O.S., *et al* (2015). Growth and yield characters of potato genotypes grown in drought and irrigated conditions of Nepal. *International Journal of Applied Science and Biotechnology*. 3(3): 513-519.
- Mahmud, A., Hossain, M., Bazzaz, M., Khan, S., Hossain, A. and Kadian, M.S. (2014). Tuber yield, tuber quality and plant water status of potato under drought and well-watered condition. *World Journal of Science Frontier Research*. 14: 2249-4626.
- Mensah, J.K., Obadoni, B.O., Eroutor, P.G. and Onome-Irieguna, F. (2006). Simulated flooding and drought effects on germination, growth and yield parameters of Sesame (*Sesamum indicum* L.). *African Journal of Biotechnology*. 5: 1249-1253.
- Maralian, H., Nasrollahzadeh, S., Yaegoob, Raiyi, Y. and Hassanpanah, D. (2014). Responses of potato genotypes to limited irrigation. *International Journal of Agronomy and Agricultural Research*. 5(5): 13-19.
- Mir, R.R., Zaman-Allah M., Sreenivasulu, N., Trethowan, R. and Varshney, R.K. (2012). Integrated genomics, physiology and breeding approaches for improving drought tolerance in crops. *Theoretical and Applied Genetics*. 125: 625-645.
- MoA (Ministry of Agriculture). (2015). Plant variety release, protection and seed quality control Directorate, Crop variety register. Issue No. 17. MoA, Addis Ababa, Ethiopia.
- Muchow R.C. (1985). Phenology, seed yield and water use of grain legumes grown under different soil water regimes in a semi-arid tropics environment. *Field Crops Research*. 11: 81-97.
- Pennisi, E. (2008). The blue revolution, drop by drop, gene by gene. *Science*. 320: 171-173.
- Rana U. and Chaudhary S. (2013). Physiological evaluation of brassica species differing in drought tolerance. *Indian Journal of Agricultural Research*. 47 (3): 200-206.
- Saravia, D., Vignolo, E.R., Gutiérrez, R., De Mendiburu, F., Schaffleitner, R., Bonierbale, M. and Khan, A.M. (2016). Yield and physiological response of potatoes indicate different strategies to cope with drought stress and nitrogen fertilization. *American Journal of Potato Research*. 93: 288-295.
- Schittenhelm, S., Sourell, H. and Lopmeier, F. J. (2006). Drought resistance of potato cultivars with contrasting canopy architecture. *European Journal of Agronomy*. 24:193-202.
- Schonfeld, M.A., Johnson, R.C., Carwer, B.F. and Mornhinweg, D.W. (1988). Water relations in winter wheat as drought resistance indicators. *Crop Science*. 28: 526-531.
- Shi, S., Fan, M., Iwama, K., Li, F., Zhang, Z. and Jia, L. (2015). Physiological basis of drought resistance in potato grown under long term water deficiency. *International Journal of Plant Production*. 9(2): 1735-6814.
- Thiele, G., Theisen, K., Bonierbale, M. and Walker, T. (2010). Targeting the poor and hungry with potato science. *Potato Journal*. 37: 75-86.
- Turner, N.C. (1974). Stomatal behavior and water status of maize, sorghum and tobacco under field conditions: at low soil water potential. *Plant Physiology*. 53: 360-365.