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Original Research

Evaluation of Potato (*Solanum tuberosum* L.) Genotypes for Yield and Tuber Quality Related Traits at Lowland, Dire Dawa, Eastern Ethiopia

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Abstract

Potato (*Solanum tuberosum* L.) produces more nutritious food on less land with short period of time, but the production in lowland areas is limited by high temperatures, because the crop is adapted to cool climates and perform best at about 20°C. The production of potato at lowland areas demands to develop heat tolerant cultivars adaptable specific to high temperatures. Therefore, this research was conducted with the objectives of evaluating the yield and tuber quality related traits of 26 potato genotypes and estimating the genetic diversity under heat stress. The experiment was conducted at Dire Dawa in 2012 during the hottest months with >26^{0}C and >33^{0}C daily average and highest temperatures, respectively. Genotypes were planted in Randomized Block Design with three replications. The presence of significant differences among potato genotypes were observed for 12 tuber yield and tuber quality related traits. The genotypes produced 7.41 to 24.3 and 4.44 to 22.52 t ha^{-1} total and marketable tuber yields, respectively, with tuber dry matter content ranged from 14.89 to 20.96%. The highest yields and tuber dry matter content were obtained from heat tolerant genotype (Vivadial). Heritability and expected genetic advance ranged from 22.35 to 87.65 and 15.24 to 54.97%, respectively, while genotypic and phenotypic coefficient of variations ranged from 13.63 to 85.54 and 16.78 to 90.97%, respectively. All the variability components values were medium to high for all traits suggested that selection genotypes on the basis of their performance was effective method to improve the crop in lowland areas. The genotypes were clustered in three groups of which Cluster I and II consisting of 11and 14 genotypes, respectively, while Vivadial formed solitary Cluster III. The research results demonstrated the existence of wider genetic variations among the potato genotypes and the higher chance of developing cultivars adaptable to lowland areas.

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INTRODUCTION

Potato (*Solanum tuberosum* L.) is highly recommended food security crop for low-income farmers and vulnerable consumers. It is one of the plant species that are the most effective in transforming the solar energy into human food (Kalaji *et al*., 2011; Brestic *et al*., 2012; Bahari *et al*., 2013). The potato is producing up to 85% of the plant part as edible human food compared to about 50% in cereals (FAO, 2009). The plant potato produces more nutritious food more quickly, on less land, and relatively harsher climates than any other major crops. Potato is major economic importance crop and number one non-grain food commodity in the world (Rykaczewska, 2013). It is the third most important food crop in terms of consumption in the world after rice and wheat (Birch *et al*., 2012; Hancock *et al*., 2014).

The Eastern Africa has over 200 million people and expected to be doubled by 2030. For this region food security is a key priority that puts increasing pressure on the fixed land for food production to feed the increasing population. This is further aggravated by the increasingly degraded environment and the uncertainties resulting from climate change. For such conditions robust crops that can adapt to a wide range of agro-ecologies in the region are required of which potato, sweet potato and cassava are the major food staple crops in the Eastern Africa countries (Kyamanywa *et al.,* 2011). However, the production of potato in the tropics and subtropics is mainly limited by heat and water stresses, because the plant is adapted typical for temperate/cool climate and does not perform well in areas with high temperatures (Koman and Haverkort, 1995; Hijmans, 2003). It develops and produced tubers best at temperatures of about 20°C (Struik *et al*., 1989; Rykaczewska, 1993; Van Dam *et al*., 1996). Although potato is extensively adapted in temperate/cool climates certain genotypes have the capacity to initiate tubers at high temperatures (Ewing *et al*., 1987) and exhibit relatively small yield losses in hot seasons (Levy, 1986). Therefore, developing potato cultivars to high temperatures of the tropics is an important task of breeders, since in vast areas of tropical Africa, the yielding capacity and the high nutritional value of the potato is much needed.

Eastern Ethiopia is one of the four major potato growing areas in the country. The eastern Ethiopia potato production is mainly covers the eastern highlands, especially East Hararghe zone (CSA, 2009). The most important feature of potato production in this region is that the potato produced is market oriented with considerable amount being exported to Djibouti and Somalia (Adane *et al.,* 2010). The larger proportion of land in eastern Ethiopia is lowland but suitable for crops production as far as water is available for irrigation. Therefore, extending of potato production to lowlands areas of eastern Ethiopia in particular and in Ethiopia in general is appropriate strategy to exploit the advantage of the crop for food and nutrition security and to increase foreign currency earnings. However, the production of potato at lowland areas is demanding the availability of heat tolerant varieties. Searching genotypes tolerant to heat is not only for potato, but also important within all crop species due to global warming heat stress is an agricultural problem in many areas in the world (Arvin and Donnelly, 2008; Birch *et al*., 2012).

The potato varieties recommended for production in Ethiopia are for middle to highland areas. These varieties might not produce reasonable yield and quality tubers at lowland since tuberization is significantly inhibited and photoassimilate partitioning to tubers is greatly reduced under high-temperature conditions (Ewing, 1981; Krauss and Marschner, 1984; Haynes *et al*., 1989; Lafta and Lorenzen, 1995; Van Dam *et al*., 1996; Rykaczewska, 2015). However, there are reports that indicate the existence of genetic variability for heat tolerance (Tai and Coleman, 1999), which could be exploited in breeding programs. Haramaya University has been introduced some heat tolerant potato cultivars and tested at lowland area along with many other genotypes. However, agronomic performance, and genetic diversity of genotypes under heat stress is not well studied. Therefore, this study was re-initiated with the objectives of evaluating the yield and tuber quality related traits performance of genotypes and estimating genetic diversity under heat stress.

MATERIALS AND METHODS

Description of the Study Area

The field experiment was conducted at Dire Dawa Agricultural Research Station of Haramaya University during the hottest months (June-October) of 2012 (Table 1). Dire Dawa is located between latitude and longitude of $9^{0}36'$ N and $41^{0}52'$ E coordinates. The altitude of Dire Dawa is 1260 meters above sea level (Hailay *et al*., 2004) and the mean annual temperatures range from 21.5^{0}C (December) to 28.4^{0}C (June).

Experimental Materials

A total of 26 genotypes were evaluated of which five were heat tolerant and one recently released potato variety, Bubu (Table 2).

Table 1: Weather data of Dire Dawa

Month	Average high °C	Daily mean °C	Average low °C	Average rainfall (mm)	Average relative humidity (%)
January	27.2	22.1	14	15	43.9
February	28	23.1	15.5	33	49.8
March	30	25.7	16.3	67	45
April	29	26.2	20	103	47
May	31	27.6	21.3	55	39.3
June	33.5	28.4	22.4	20	37.6
July	32	27.1	20.6	80	41.4
August	31	26.1	20.1	117	45.1
September	29.9	26.5	20.5	60	39.7
October	28.5	25.7	19.5	19	31.3
November	27.5	22.9	15.7	17	39.1
December	27	21.5	15	8	42.6
Year	**29.55**	**25.24**	**18.41**	**594**	**41.82**

Source: Levoyageur Weather (2012).

Table 2: List of potato genotypes evaluated at Dire Dawa in 2012

No.	Genotype	No.	Genotype	Remark
1	CIP-392640-516	14	AL-100	
2	CIP-392640-541	15	AL-348	
3	CIP-392640-528	16	AL-503	
4	CIP-386029-18c	17	AL-209	
5	CIP-392140-526	18	AL-269	Genotypes with initial AL are the old potato accessions introduced before 1975 while with CIP initial were introduced from International Center for Potato (CIP) at different periods.
6	CIP-392640-525	19	AL-119	
7	CIP-378371-9c	20	AL-270	
8	CIP-378323-2B	21	HU19	
9	CIP-378501-10A	22	HU16	Genotypes with initial HU were introduced at different periods as heat tolerant accessions but information is not available.
10	CIP-391058-506	23	HU1	
11	CIP-391058-520	24	HU14	
12	CIP-392037-500	25	Vivadial	Heat tolerant accession
13	CIP-378371-19	26	Bubu	Released in 2011 for mid to highland areas

Experimental Design

The experiment was laid out as a Randomized Complete Block Design (RCBD) where each genotype was replicated three times. Each plot was 3.60 x 4.50 m (16.2 m^2) consisting of six rows, that contained a total of 12 plants per row and 72 plants per plot. The spacing between plots and adjacent replications were 1.0 and 1.5 m, respectively.

Medium-sized and well sprouted potato tubers were planted at the spacing of 75 cm between rows and 30 cm between plants. The planting depth was maintained at 5 to 10 cm. The whole recommended rate of Phosphorus fertilizer (92 kg P_2O_5 ha^{-1}) was applied at planting in the form of Diammonium Phosphate. Nitrogen fertilizer was applied at the rate of 75 kg N ha^{-1} in the form of Urea in two splits, half rate after full emergence (two weeks after planting) and half rate at the initiation of tubers. The irrigation water is applied every three days and all agronomic practices were applied as per the recommendation made by the Haramaya University for the region.

Data Collection

Days to 50% of plants flowering was recorded as the number of days of planting to 50% of the plants produced flowers in each plot. Plant height was measured from 10 randomly selected plants in the central rows during 50% of the plants attained physiological maturity in each plot. The total tuber yield of each genotype was taken from plants in the four middle rows. Tubers were carefully collected after the hills were dug by hand. The collected total tubers in each plot were weighted and converted to tons per hectare. Tubers which were free from diseases, insect pests, and greater than or equal to 20g in weight were sorted, and weighed for each plot and converted as marketable yield (t ha^{-1}). The remaining tubers (diseased, insect-attacked and small-sized, i.e. <20 g) were recorded as unmarketable tuber yield (t ha^{-1}). Percent marketable and unmarketable tuber yields were calculated as proportion of the two yields to total tuber yield. Number of total, marketable, and unmarketable tubers were divided by the number of harvested plants and recorded as number of tubers per plant.

Tuber dry matter content (%) was measured from five fresh tubers in each plot. The randomly selected tubers were weighed at harvest, sliced and dried in oven at 75°C until a constant weight was attained and dry matter in percent was calculated according to Williams and Woodbury (1968) as follows.

$$\text{Dry matter (\%)} = \frac{Weight of\ sample after\ drying(g)}{Intial weight of\ sample(g)} \times 100$$

Total starch content (g/100g) was estimated from dry matter content. Starch content (g/100g) = 17.55 + 0.891 * (tuber dry weight % – 24.182) (AOAC, 1980) where dry matter content was determined as indicated above. The total starch yield was recorded as the multiple of starch content and total yield t ha^{-1}.

Data Analysis

Data collected for 13 traits were subjected to analysis of variance which was computed with SAS statistical software (9.1). Phenotypic and genotypic variance, coefficient of variation, heritability, and genetic advance were computed using the excel microsoft program. Mean separation was employed following the significance of mean squares using Least Significant Differences (LSD) at 5% probability. Euclidean distances depicting genetic relationships among 26 potato genotypes based on 12 traits and dendrogram was generated based on Unweighted Pair-group Method with Arithmetic means (UPGMA) were computed using STATISTICA-7 basic statistical analysis software (U.S.A.).

The phenotypic and genotypic variances and coefficients of variations were estimated according to the methods suggested by Burton and Devane (1953). Heritability (H^2) in broad sense was computed using the formula adopted by Allard (1960) and Falconer (1990), and genetic advance (GA) for each trait was computed using the formula adopted by Johnson *et al*. (1955) and Allard (1960) as follows:

$$\sigma^2_g = M_g - M_e / r \text{ and } \sigma^2_p = \sigma^2_g - \sigma^2_e$$

where; σ^2_p= phenotypic variance, σ^2_g= genotypic variance, σ^2_e environmental variance/error mean square, M_g= mean square of genotypes, and M_e= mean square of error, r = number of replications. Phenotypic coefficient of variation (PCV) = $\frac{\sqrt{\sigma^2 p}}{X} x100$ and genotypic coefficient of variation, GCV= $\frac{\sqrt{\sigma^2 g}}{X} x100$ were also calculated where x= population mean.

Heritability in broad sense was computed as $H^2 = [\sigma^2_g / \sigma^2_p] \times 100$, where; H^2 is heritability in broad sense, σ^2_g = genotypic variance, and $\sigma^2 p$ = phenotypic variance. Genetic advance as part of the mean (GA) for each trait was computed as GA = (k) (σ_p)* (H^2), and GAM (genetic advance as % of the mean) = $\frac{GA}{X}$ X100 where k = selection differential (k =2.06 at 5% selection intensity), σ_p = phenotypic standard deviation, H^2 = heritability in broad sense, and x = grand mean of each trait.

Genetic distance of 26 potato genotypes was estimated using Euclidean distance (ED) calculated from the 12 traits after standardization (subtracting the mean value and dividing it by the standard deviation) as established by Sneath and Sokal, (1973) as follows:

$$ED_{jk} = \sqrt{\sum_{i=1}^{n} (Xij - Xik)^2}$$

Where, ED_{jk} = distance between genotypes j and k; x_{ij} and x_{ik}= phenology, growth, tuber yield and tuber quality related traits mean values of the ith trait for genotypes j and k, respectively; and n= number of traits used to calculate the distance. The distance matrix from tuber phenology, growth, yield and tuber quality related traits was used to construct dendrograms based on the Unweighted Pair-group Method with Arithmetic means (UPGMA). The results of the cluster analysis were presented in the form of dendrogram. In addition, mean average distance (ED) was calculated for each genotype by averaging the distance of a particular potato genotype over the other 25 genotypes. The calculated average distance was used to estimate which potato genotype is closest or distant to the others.

RESULTS

Analysis of Variance

The mean squares from analysis of variance for 13 traits of 26 potato genotypes are presented in Table 3. The results revealed the presence of significant differences among potato genotypes for all traits except for number of unmarketable tuber/plant.

Table 3. Mean squares from analysis of variance for 13 traits of 26 potato genotypes

Trait	Replication (2)	Genotype (25)	Error (50)	CV (%)
Days to 50% flowering	2.705	39.68**	2.74	4.3
Plant height (cm)	9.00	124.88**	7.60	4.8
Total tuber yield t ha^{-1}	210.73	56.15*	23.35	22.1
Marketable tuber yield t ha^{-1}	271.96	66.35**	21.20	20.5
Unmarketable tuber yield t ha^{-1}	1.79	2.024**	0.59	20.6
Total tuber number/plant	0.31	3.03**	0.16	6.0
Number of marketable tuber /plant	0.08	3.79**	0.17	10.6
Number of unmarketable tuber/plant	1.33	2.51	1.63	28.5
Percent marketable tuber yield (%)	207.67	379**	131.50	17.7
Percent unmarketable tuber yield (%)	103.76	92.1**	38.60	16.4
Tuber dry matter content (%)	6.79	43.23**	2.31	8.5
Starch content (g/100g)	5.39	32.26**	1.83	11.4
Starch total yield t ha^{-1}	1.258	1.034**	0.16	19.8

* and **, significant at $p<0.05$ and $p<0.01$, respectively.
CV (%) = coefficient of variation in percent and numbers in parenthesis represented degree of freedom

Mean Performance of Genotypes

The 26 potato genotypes exhibited a wide range of mean values for all traits. The genotypes total tuber yield was ranged from 7.4 to 24.3 t ha^{-1} (Table 4) with the overall mean total tuber yield of 12.89 t ha^{-1} (Table 5), whereas marketable and unmarketable tuber yields were ranged from 4.44 to 22.52 and 0.62 to 3.85 t ha^{-1}, respectively. The proportion of marketable and unmarketable tuber yields were also exhibited wide variations that ranged between 48.95 and 94.08 and 5.93 and 51.22%, respectively. Tuber dry matter and starch contents of genotypes ranged from 14.89 to 20.96% and 9.27 to 20.96g/100g, respectively, whereas total starch yield ranged from 0.79 to 3.44 t ha^{-1} (Table 4). The variations among the 26 potato genotypes were also large for other traits. The highest total and marketable tuber yields as well as total starch yield t ha^{-1} were obtained from Vivadial (heat tolerant genotype).

The four heat tolerant genotypes other than Vivadial produced 11.26 to17.18 and 7.41 to16 t ha^{-1} total and marketable tuber yield, respectively (Table 4). Two potato genotypes produced total and marketable tuber yield more than the four heat tolerant genotypes. The improved potato variety (Bubu) produced total and marketable tuber yield lower than heat tolerant genotypes and other five genotypes. The heat tolerant genotypes were early flowering than most of the other genotypes.

Variability Components

The phenotypic and genotypic coefficient of variations ranged between 16.78 and 90.97 and 13.63 and 85.54%, respectively. Both highest phenotypic and genotypic coefficient of variations were computed for starch content of tubers while the lowest phenotypic and genotypic coefficient of variations were recorded for total number of tubers per plant and unmarketable tuber yield t ha^{-1}, respectively (Table 5). The phenotypic coefficient of variation was higher than genotypic coefficient of variation for all traits.

The estimated heritability value was highest for marketable number of tubers per plant (87.65%) while the lowest was computed for unmarketable tuber yield t ha^{-1} (22.35%). The heritability in broad sense values were >31% for the remaining 10 traits. The genetic advance as percent mean values ranged from 15.24 to 54.97% for all traits. The lowest and highest genetic advance values were recorded for percent marketable tuber yield and marketable number of tubers per plant, respectively.

Genetic Distance of Potato Genotypes

Estimates of genetic distance measured from Euclidean distance varied from 1 to 10.1 with mean and standard deviation of 4.63 and 1.61, respectively. The highest genetic distance was registered for Vivadial and CIP-386029-18c followed by Vivadial and CIP-391058-506 as well as Vivadial and Al-100 (9). The lowest distance was calculated for Al-100 and CIP-386029-18c, followed by CIP-392640-516 and CIP-378501-10A (1.04), Al-269 and HU14 (1.2), CIP-392640-516 and HU1 (1.36). The mean Euclidean distance result showed that the closest genotypes to others were CIP-378501-10A (3.55) followed by CIP-392640-516 (3.74) and HU1 (3.81) while the most distant to others were Vivadial (7.38) followed by HU19 (5.41) and CIP-386029-18c (5.37). Vivadial had Euclidean distance <5.34 only with HU16 and CIP-392140-526 (Table 6). Among 325 pairs of genotypes 177 and 148 pairs had <4.63 and $\geq$4.63 distances, respectively.

The dendrogram constructed from Unweighted Pair-group Method with Arithmetic means (UPGMA) based on the Euclidean distance matrix is presented in Figure 1. Clustering resulted in the formation of three major groups of genotypes, of which Cluster I comprised 11 genotypes and Cluster II consisted of 14 hat subdivided in to two of which Subgroup I and II consisted of 6 and 8 genotypes, respectively. Vivadial formed a solitary Cluster III while the other four heat tolerant genotypes were distributed in two clusters. None of the old potato accessions (with initial AL-) grouped in Cluster I rather distributed in the two sub-groups of cluster II. Bubu (improved variety) was grouped in Cluster I with one heat tolerant accession (HU16).

Cluster I was characterized by higher mean performance than overall mean of genotypes except for unmarketable tuber yield (t ha^{-1}) and percent unmarketable tuber yield which was desired in selection of genotypes. The members of this cluster had total and marketable tuber yield of 12.77 to 21.63 and 11.25 to 19.85 t ha^{-1}, respectively. Cluster II was characterized by

Table 4: Mean performance of 26 potato genotypes evaluated at Dire Dawa (2012) for 12 traits

Genotype	DF	PLH (cm)	TTY (t ha^{-1})	MTY (t ha^{-1})	UNMTY (t ha^{-1})	TN/plant	MTN/plant	PMTY (%)	PUNMTY (%)	DM (%)	SC (g/100g)	STY (t ha^{-1})
CIP-392640-516	40.67^{b-e}	59.09^{d-g}	13.04^{c-f}	11.25^{c-h}	1.78^{g}	7.6b^{c}	4.73^{bcd}	85.21^{a-f}	14.76^{e-j}	18.54^{a-g}	12.52^{a-g}	1.65^{b-f}
HU19	34^{h}	60.68^{de}	11.26^{c-f}	7.41^{d-h}	3.85^{a}	7.67^{abc}	3.53^{fgh}	64.39^{e-j}	35.64^{a-f}	20.96^{a}	14.68^{a}	1.64^{b-f}
HU16	34^{h}	66.43^{b}	17.18^{a-d}	16^{abc}	1.15^{h}	7.13^{b-f}	5.33^{b}	93.17^{ab}	6.88^{ij}	17.34^{d-i}	11.46^{d-i}	1.92^{bcd}
Al-100	34.67^{gh}	66.2^{bc}	7.41^{f}	4.44^{h}	3.27^{bc}	6.13^{d-h}	2.53^{ij}	52.7^{ij}	47.34^{ab}	17.36^{d-i}	11.47^{d-i}	0.79^{f}
CIP-392640-541	38^{ef}	61.89^{cde}	15.7^{b-e}	13.33^{b-e}	2.37^{ef}	8.33^{ab}	5.2^{bc}	86.02^{a-e}	13.96^{f-j}	17.95^{c-h}	11.99^{c-h}	1.91^{bcd}
Al-348	37^{fg}	71.4^{a}	13.33^{c-f}	10.96^{c-h}	2.37^{ef}	6.07^{e-h}	2.87^{hi}	67.87^{d-j}	32.31^{a-g}	17.26^{d-i}	11.38^{d-i}	1.46^{c-f}
AL-503	34^{h}	52.9^{ijk}	10.37^{c-f}	6.82^{e-h}	3.56^{ab}	7.33^{b-e}	3g^{hi}	63.82^{f-j}	36.24^{a-e}	15.7^{hi}	9.99^{hi}	1.03^{c-f}
CIP-392640-528	39.33^{c-f}	62.57^{bcd}	15.14^{b-f}	14.52^{bcd}	0.62^{i}	5.8^{fgh}	4.4^{d}	94.08^{a}	5.93^{i}	17.55^{d-h}	11.64^{d-h}	1.74^{b-f}
CIP-386029-18c	34^{h}	66.13^{bc}	7.4^{f}	4.74^{gh}	2.67^{de}	5.6^{gh}	2.4^{ij}	48.95^{j}	51.22^{a}	17.24^{d-i}	11.36^{d-i}	0.85^{ef}
AL-209	36.67^{fgh}	45.07^{m}	9.78^{def}	6.22^{e-h}	3.56^{ab}	6.67^{c-g}	2.87^{hi}	54.92^{hij}	45.18^{abc}	18.81^{a-f}	12.76^{a-f}	1.25^{c-f}
CIP-392140-526	38^{ef}	52.93^{ijk}	21.63^{ab}	19.85^{ab}	1.78^{g}	7.4^{b-e}	5.27^{bc}	91.82^{abc}	8.18^{hij}	17.25^{d-i}	11.37^{d-i}	2.48^{ab}
CIP-392640-525	38^{ef}	55.3^{f-k}	17.78^{abc}	16^{abc}	1.78^{g}	6.8^{c-g}	5.27^{bc}	90.22^{abc}	9.78^{hij}	16.52^{f-i}	10.72^{f-i}	1.91^{bcd}
Al-269	41.33^{bc}	53.56^{ijk}	13.63^{c-f}	10.07^{c-h}	3.55^{ab}	6.33^{c-h}	3.67^{efg}	66.72^{d-j}	33.24^{a-g}	16.3^{ghi}	10.52^{ghi}	1.39^{c-f}
CIP-378371-9c	42.67^{b}	54.7^{g-k}	7.4^{f}	5.04^{fgh}	2.37^{ef}	7^{b-f}	2.13^{j}	67.25^{d-j}	32.92^{a-g}	20.81^{ab}	14.55^{ab}	1.061^{c-f}
Al-119	42.67^{b}	55.73^{f-j}	8.59^{ef}	6.82^{e-h}	1.78^{g}	7.2^{b-e}	3.4^{gh}	71.93^{b-i}	28.2^{b-i}	18.45^{b-g}	12.45^{b-g}	1.0^{c-f}
CIP-378323-2B	39^{c-f}	62.13^{bcd}	12.77^{c-f}	11.85^{c-h}	0.92^{hi}	5.53^{gh}	4.13^{def}	93.63^{ab}	6.4^{ij}	16.65^{e-i}	10.84^{e-i}	1.38^{c-f}
Al-270	39^{c-f}	51.29^{jkl}	9.33^{def}	6.67^{e-h}	2.67^{de}	5.6^{gh}	2.9^{hi}	70.13^{c-j}	29.95^{a-h}	14.89^{i}	9.27^{i}	0.86^{ef}
Vivadial	34^{h}	59.76^{def}	24.3^{a}	22.52^{a}	1.78^{g}	9^{a}	6.33^{a}	92.59^{ab}	7.41^{ij}	20.08^{abc}	13.9^{abc}	3.44^{a}
CIP-378501-10A	41^{bcd}	58.81^{d-h}	14.52^{b-f}	12.44^{b-f}	2.08^{fg}	7.47^{bcd}	4.6^{cd}	80.47^{a-g}	19.59^{d-j}	17.$^{8c-h}$	11.86^{c-h}	1.63^{b-f}
CIP-391058-506	47.67^{a}	47.67^{lm}	8^{ef}	6.22^{e-h}	1.78^{g}	5^{h}	2.67^{ij}	76.39^{a-h}	23.63^{c-j}	17.52^{d-h}	11.61^{d-h}	0.85^{ef}
CIP-391058-520	38.33^{def}	50.97^{kl}	15.73^{b-e}	13.33^{b-e}	2.40^{ef}	6.07^{e-h}	4.33^{de}	87.73^{a-d}	12.28^{g-j}	18.66^{a-g}	12.63^{a-g}	1.99^{bc}
CIP-392037-500	39^{c-f}	47.93^{lm}	13.63^{c-f}	11.56^{c-h}	2.08^{fg}	7.47^{bcd}	4.47^{d}	83.09^{a-g}	17^{d-j}	15.92^{hi}	10.19^{hi}	1.37^{c-f}
HU1	39^{c-f}	61.97^{bcd}	13.96^{b-f}	11.85^{c-h}	2.37^{ef}	7^{b-f}	4.67^{bcd}	84.23^{a-f}	17.53^{d-j}	19.17^{a-d}	13.09^{a-d}	1.83^{b-e}
HU14	41.67^{bc}	55.27^{f-k}	11.85^{c-f}	8.89^{c-h}	2.97^{cd}	6.13^{d-h}	3.6^{fg}	61.13^{g-j}	38.9^{7ad}	16.24^{ghi}	10.47^{ghi}	1.25^{c-f}
CIP-378371-19	41^{bcd}	54.4^{h-k}	7.7^{f}	5.33^{fgh}	2.3^{7ef}	5.07^{h}	2.4^{ij}	66.5^{d-j}	33.58^{a-g}	19.02^{b-e}	12.95^{b-e}	0.97^{def}
Bubu	46^{a}	57.37^{e-i}	13.78^{b-f}	12^{c-g}	1.78^{g}	5.6^{gh}	3.5^{fgh}	86.6^{a-d}	13.42g^{-j}	18.67^{a-g}	12.64^{a-g}	1.73^{b-f}
LSD (5%)	**2.72**	**4.52**	**7.98**	**7.55**	**0.48**	**0.66**	**0.67**	**22.1**	**22.1**	**2.49**	**2.22**	**0.99**

Means with similar letter(s) in a column are not significantly different, LSD (5%), least significant difference, DF = days to 50% flowering, PLH (cm) = plant height, TTY (t ha^{-1}) = total tuber yield tons per hectare, MTY (t ha^{-1}) = marketable tuber yield, UNMTY (t ha^{-1}) = unmarketable tuber yield tons per hectare, TN/plant = total tuber number per plant, NMT/plant = number of marketable tubers per plant, PMTY (%) = percent marketable tuber yield, PUNMTY (%) = percent marketable tuber yield, DM (%) = tuber dry matter content, SC (%) = starch content of tubers and STY (t ha^{-1}) = total starch yield tons per hectare

Table 5: Variability components for 12 traits of 26 potato genotypes evaluated at Dire Dawa (2012)

Trait	Mean	Minimum	Maximum	GV	PV	GCV	PCV	H_2 (%)	GAM (5%)
DF	38.87	34	47.67	12.31	15.06	31.67	38.73	81.77	16.81
PLH (cm)	57.39	45.07	71.4	39.09	46.69	68.12	81.36	83.72	20.54
TTY (t ha^{-1})	12.89	7.4	24.3	8.17	21.82	63.34	69.22	37.43	27.94
MTY (t ha^{-1})	10.62	4.44	22.52	5.05	16.25	47.55	53.01	31.08	24.3
UNMTY (t ha^{-1})	2.29	0.62	3.85	0.31	1.4	13.63	60.95	22.35	23.73
TN/plant	6.65	5	9	0.96	1.12	14.38	16.78	85.67	28.03
MTN/plant	3.85	2.13	6.33	1.21	1.38	31.31	35.72	87.65	54.97
PMTY (%)	76.2	48.95	94.08	82.5	114.04	58.25	80.79	38.55	15.24
PUNMTY (%)	23.9	5.93	51.22	17.83	56.43	24.6	36.07	31.6	20.46
DM (%)	17.79	14.89	20.96	13.64	15.95	76.66	89.62	85.53	39.54
SC (g/100g)	11.86	9.27	14.68	10.14	11.97	85.54	90.97	84.72	50.92
STY (t ha^{-1})	1.51	0.793	3.435	0.22	0.59	14.79	38.69	38.23	39.8

GV = genetic variance, PV = phenotypic variance, GCV = genetic coefficient of variation, PCV = phenotypic coefficient of variation, H2 (%) = heritability in broad sense, GAM (5%) = genetic advance as percent mean at 5% selection intensity, DF = days to 50% flowering, PLH (cm) = plant height, TTY (t ha^{-1}) = total tuber yield tons per hectare, MTY (t ha^{-1}) = marketable tuber yield, UNMTY (t ha^{-1}) = unmarketable tuber yield tons per hectare, TN/plant = total tuber number per plant, NMT/plant = number of marketable tubers per plant, PMTY (%) = percent marketable tuber yield, PUNMTY (%) = percent marketable tuber yield, DM (%) = tuber dry matter content, SC (%) = starch content of tubers and STY (t ha^{-1}) = total starch yield tons per hectare.

Table 6: Euclidean distance of 26 potato genotypes measured from 12 traits and mean Euclidean distance obtained by averaging each genotype distance to other 25 potato genotypes as evaluated at Dire Dawa in 2012

Genotype	HU19	HU16	Al-100	CIP-392640-541	Al-348	AL-503	CIP-39264-528	CIP-386029-18c	AL-209	CIP-392140-526	CIP-392640-525	Al-269
CIP-392640-516 **(3.74)**	4.63	3.13	5.60	1.74	3.87	5.07	2.85	5.9	5.10	3.59	2.83	4.02
HU19		6.33	4.53	4.78	4.76	5.24	6.65	5.1	3.67	6.80	6.45	5.22
HU16			6.76	2.57	4.32	6.11	2.41	6.9	7.13	2.98	2.36	5.54
Al-100				5.97	3.13	3.26	6.59	1.0	3.81	7.85	6.64	3.99
CIP-392640-541					4.07	5.03	3.53	6.4	5.67	2.97	2.53	4.25
Al-348						4.08	4.12	3.2	4.98	5.60	4.52	3.55
AL-503							6.24	3.7	3.46	6.39	5.22	2.69
CIP-392640-528								6.6	6.78	3.57	2.58	5.12
CIP-386029-18c									4.13	8.01	6.79	4.37
AL-209										6.93	6.21	3.54
CIP-392140-526											1.84	5.21
CIP-392640-525												4.11
Mean ED	**5.41**	**4.84**	**5.16**	**4.16**	**4.30**	**4.83**	**4.50**	**5.37**	**5.00**	**5.11**	**4.29**	**4.11**

	CIP-378371-9c	Al-119	CIP-378323-2B	Al-270	Vivadial	CIP-378501-10A	CIP-391058-506	CIP-391058-520	CIP-392037-500	HU1	HU14	CIP-378371-19	Bubu
CIP-392640-516	4.4	2.67	3.18	5.2	5.6	1.04	4.79	2.45	3.12	1.36	4.14	4.47	2.73
HU19	3.73	4.53	6.78	6.74	7.2	4.75	6.82	4.81	6.2	3.82	5.38	4.59	5.72
HU16	7.04	5.29	3.02	6.25	4.9	3.16	6.95	3.7	4.17	3.2	5.71	6.54	4.67
Al-100	4.79	4.22	5.94	4.08	9.9	5.23	5.62	5.99	5.75	5.29	3.47	3.64	6.05
CIP-392640-541	5.65	4.03	3.9	5.71	4.7	1.65	6.18	3	3.31	1.93	4.62	5.7	4.04
Al-348	5.05	3.79	3.79	4.25	7.7	3.41	5.31	4.37	4.65	3.47	3.27	3.98	4.19
AL-503	5.69	4.27	5.51	2.68	9	4.47	5.46	5.12	3.64	5.16	2.75	4.63	5.97
CIP-392640-528	6.15	4.37	1.41	5.49	6.2	2.95	5.19	3.14	3.95	3.16	5.1	5.33	2.96
CIP-386029-18c	5.08	4.46	5.91	4.16	10.1	5.53	5.65	6.2	5.98	5.61	3.68	3.67	6.18
AL-209	3.63	3.75	6.48	4.47	8.9	4.82	4.86	4.7	4.92	4.89	3.52	3.2	5.46
CIP-392140-526	7.37	5.75	4.31	6.5	4	3.3	6.87	3.08	3.71	3.78	5.71	7	4.55
CIP-392640-525	6.71	4.7	2.82	5	5.4	2.39	5.7	2.63	2.44	3.2	4.48	5.93	3.84
Al-269	5.11	3.51	4.59	2.62	8.2	3.2	4.07	3.8	3.03	4.04	1.12	3.86	4.09
CIP-378371-9c		2.69	6.1	5.94	8.8	4.67	4.29	4.92	5.9	4.31	4.87	2.61	4.31
Al-119			4.06	4.08	8	2.72	3.11	3.82	3.65	3.21	3.13	2.6	3.14
CIP-378323-2B				4.44	7.3	3.12	4.58	3.49	3.51	3.58	4.48	4.88	3.19
Al-270					9.8	4.6	3.76	5.06	3.42	5.51	2.27	4.07	5.1
Vivadial						5.81	9.9	5.59	7.1	5.34	8.65	9.28	7.08
CIP-378501-10A							4.63	2.42	2.57	1.67	3.39	4.41	2.76
CIP-391058-506								4.74	4.56	5.22	3.69	2.85	3.34
CIP-391058-520									3.27	2.16	4.24	4.35	2.69
CIP-392037-500										3.88	3.32	5.09	4.16
HU1											4.26	4.31	2.85
HU14												3.42	4.14
CIP-378371-19													3.72
Mean ED	**5.19**	**3.98**	**4.42**	**4.85**	**7.38**	**3.55**	**5.13**	**3.99**	**4.21**	**3.81**	**4.11**	**4.56**	**4.28**

Table 7: Range, mean performance and standard deviation of three clusters consisting 26 potato genotypes for 12 traits evaluated at Dire Dawa (2012)

Trait	Cluster I			Cluster II						Overall Cluster III		Cluster III	Overall genotypes	
				Sub-group I			Sub-group II							
	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Mean	SD	Mean	Mean	SD
DF	34-46	39.21	2.9	34-47.67	40.78	4.85	34-41.67	37.58	3.15	38.95	4.13	34	38.87	3.64
PLH (cm)	50.97-66.43	59.04	4.61	45.07-60.68	53.04	5.7	47.93-71.4	58.09	8.56	55.92	7.66	59.76	57.39	6.45
TTY (t ha^{-1})	12.77-21.63	15.57	2.56	7.4-11.26	8.79	1.47	7.4-13.63	10.87	2.64	9.98	2.4	24.3	12.89	4.33
MTY (t ha^{-1})	11.25 -19.85	13.86	2.58	5.04-7.41	6.17	0.89	4.44-11.56	8.02	2.75	7.23	2.3	22.52	10.62	4.7
UNMTY (t ha^{-1})	0.62-2.4	1.73	0.6	1.78-3.85	2.62	0.89	2.08-3.56	2.89	0.54	2.78	0.69	1.78	2.29	0.82
TN/plant	5.53-8.33	6.79	0.92	5-7.67	6.44	1.13	5.6-7.47	6.33	0.71	6.38	0.88	9	6.65	1.01
MTN/plant	3.5-5.33	4.68	0.57	2.13-3.53	2.83	0.55	2.4-4.47	3.18	0.69	3.03	0.64	6.33	3.85	1.12
PMTY (%)	80.47-94.08	88.47	4.44	54.92-76.39	66.9	7.29	48.95-83.09	64.3	10.6	65.41	9.09	92.59	76.21	13.89
PUMTY (%)	5.93-19.59	11.7	4.63	23.63-45.18	33.19	7.3	17-51.22	35.78	10.61	34.67	9.1	7.41	23.91	13.89
DM (%)	16.52-19.17	17.83	0.86	17.52-20.96	19.26	1.36	14.89-17.36	16.36	0.88	17.61	1.83	20.08	17.79	1.51
SC (g/100g)	10.72-13.09	11.89	0.77	11.61-14.68	13.17	1.21	9.27-11.47	10.58	0.78	11.69	1.63	13.9	11.86	1.34
STY (t ha^{-1})	1.38-2.48	1.83	0.28	0.85-1.64	1.13	0.28	0.79-1.46	1.13	0.27	1.13	0.27	3.44	1.51	0.59

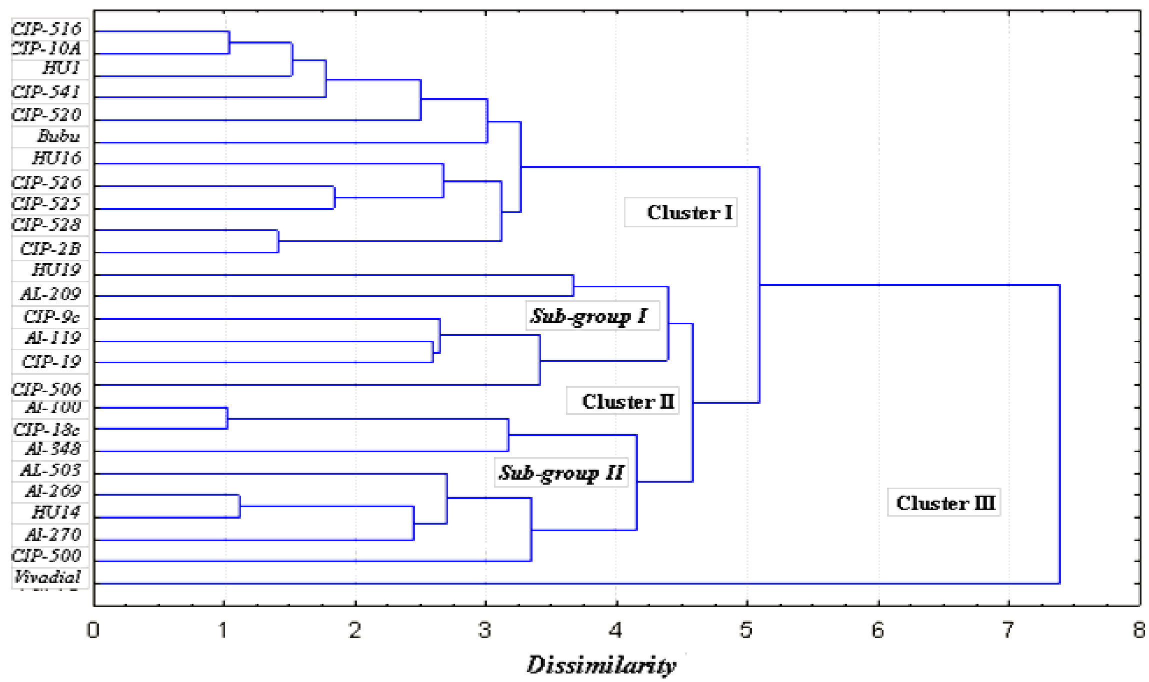

Figure 1: Dendrogram generated based on UPGMA clustering method depicting relationship among 26 potato genotypes based on 12 traits

lower mean performance for all traits than overall mean of genotypes except days to 50% plants flowering, unmarketable tuber yield (t ha-^{1}) and percent unmarketable tuber yield. Subgroup I in Cluster II was differentiated from Subgroup II with delayed flowering and higher mean values for tuber dry matter and starch content than overall mean values of genotypes. Vivadial had the highest mean values for all traits except for days to 50% plants flowering, unmarketable tuber yield (t ha^{-1}) and percent unmarketable tuber yield (Table 7).

DISCUSSION

The presence of significant variation among 26 potato genotypes was observed from the analysis of variance results, and variability components (phenotypic and genotypic coefficients of variation, heritability and genetic advance as per cent of mean). This indicating the differences of genotypes for tuber yield, and other traits at lowland (high temperatures) were due to genetic differences. Potato is extensively adapted to cool temperatures and many authors reported that tuberization is significantly inhibited and photoassimilate partitioning to tubers is greatly reduced under high-temperature conditions (Ewing, 1981; Krauss and Marschner, 1984; Haynes *et al*., 1989; Lafta and Lorenzen, 1995; Van Dam *et al*., 1996; Rykaczewska, 2015). However, there are reports that indicate the existence of genetic variability for heat tolerance (Ewing *et al*., 1987; Levy *et al*., 1991; Rykaczewska, 2013), which is in agreement with the current study results. This showed that the higher chance of obtaining cultivars that are specifically adaptable to high temperatures for tuber production.

The highest tuber yield was obtained from one heat tolerant genotype and other four heat tolerant genotypes also produced reasonable higher tuber yield than most of the tested potato genotypes. However, two potato genotypes that were under maintenance and not identified as heat tolerant produced higher tuber yield than the four heat tolerant genotypes, while the improved potato variety (Bubu) produced tuber yield lower than heat tolerant genotypes. This might be due to the genetic differences of some genotypes in tolerating heat to produce tuber yield with minimum reduction while others failed due to high temperature. It was reported the existence of genetic control of heat tolerance (Levy *et al*., 1991) and certain genotypes have the capacity to initiate tubers at high temperatures (Ewing *et al*., 1987) and exhibit relatively small yield losses in hot seasons (Levy, 1986).

The mean dry matter and starch contents of tubers were 17.79 and 11.86%, respectively, and considerable number of genotypes produced tubers as low as 14.89 and 9.27% dry matter and starch contents, respectively. Only three genotypes (two heat tolerant genotypes and one other) produced tubers with near to 21 and 14% dry matter and starch contents, respectively. This might be due to the effect of high temperatures that resulted competition of parts of plants for assimilates. When potato grow under high temperatures, it produced tall plants with long internodes, increased leaf and stem growth and more assimilates will be partitioned to foliage growth (Tsegaw *et al.*, 2005). Therefore, at high temperatures accumulation of dry matter to tubers is restricted (Menzel, 1985; Kooman & Haverkort, 1995), reduce specific gravity and reducing the total amount of starch incorporation into the tuber tissue (Thornton, 2001; Levy and Veilleux, 2007). This is due to reduced sink strength under high temperatures (Schafleinter *et al*., 2013). High dry matter content increases chip yield, crispy consistency, and reduces oil absorption during cooking (Pedreschi *et al*., 2005; Rommens *et al*., 2010). Potato cultivars with a dry matter content of 20% or higher, and starch content of 13% and above are the most preferred for processed products (Kirkman, 2007; Freitas *et al*., 2012). Therefore, only few potato genotypes were producing tubers suitable for processing, while others produced tubers suitable for boiling since they had tubers with low starch content (up to 12.0%) (Esendal, 1990).

The phenotypic coefficient of variation was higher than genotypic coefficient of variation for all traits. According to the category of GCV and PCV proposed by Sivasubramanian and Menon (1973), both GCV and PCV values were high (>20%) for all traits except both values were moderate for total tuber number per plant while moderate genotypic but high phenotypic coefficients of variations for unmarketable tuber yield and starch yield t ha^{-1}. On the other hand, as Robinson *et al.* (1949) and Johnson *et al.* (1955) suggested, both heritability and genetic advance as percent mean values were high for plant height, total and marketable tuber number per plant, tuber dry matter and starch contents. Moderate heritability was coupled either with high or moderate genetic advance as percent mean for all other traits except high heritability to moderate genetic advance for days to 50% plants flowering and low heritability was coupled with high genetic advance for unmarketable tuber yield t ha^{-1}. The observed high phenotypic and genotypic coefficient of variations for all the traits showed that the expressions of the traits were mainly the function of genetic factors. This in turn indicates the presence of substantial genetic variability among the tested potato genotypes. Though heritability of a character determines the extent to which it is transmitted from one generation to the next, heritability is a valuable tool when used in conjunction with genetic advance expectations from selection in predicting genetic gain that follows in the selection for that character (Ansari *et al,* 2004; Singh and Upadhyay, 2013). As suggested by Panse (1957) the observed high genetic advance coupled with high heritability is an indication of more additive gene action. Therefore, the improvement of the traits is possible through selection since high heritability was coupled with high genetic advance as percent mean.

The 26 potato genotypes exhibited large genetic distances under the prevalence of hot temperatures throughout the growing period. The heat tolerant genotype Vivadial formed a solitary cluster that might indicated the genetic selection of the genotype for the adaptation of high temperatures. On the other hand, the 11 potato genotypes grouped under Cluster I including the improved potato variety, and one heat tolerant genotype produced reasonably high total and marketable tuber yield up to 21.63 and 19.85 t ha^{-1}, respectively, with relatively higher tuber dry matter and starch content. These genotypes can be considered for future breeding as far as their yield potential under heat stress is better than the average national potato yield (<10 t ha^{-1}) for middle and high altitudes (Baye and Gebremedhin, 2013). The research result encourages the breeders to test large number of potato genotypes at lowland areas to develop cultivars adaptable to high temperatures. This suggestion is supported with other researchers that heat tolerance in potato is a function of genetic control (Levy *et al*., 1991), certain genotypes have the capacity to initiate tubers at high temperatures (Ewing *et al*., 1987) and exhibit relatively small yield losses in hot seasons (Levy, 1986).

CONCLUSION

Our study showed the presence of genetic variability among potato genotypes. It also showed the higher chance of selecting genotypes for high tuber yield with acceptable tuber quality through introduction of heat tolerant genotypes identified elsewhere in the world. This encourages potato breeders to introduce heat tolerant genotypes and test with the available materials in the country to develop varieties tolerant to heat.

Conflict of Interest

Conflict of interest none declared.

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