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PRELIMINARY ANALYSIS OF GENOTYPIC AND PHENOTYPIC CORRELATION OF TRAITS IN DROUGHT TOLERANT POTATO UNDER MOISTURE DEFICIT AREAS OF NORTH-WESTERN ETHIOPIA

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ABSTRACT : This study was conducted at Adet Agricultural Research Center, Simada (NW-Ethiopia) a site for drought experiments in the 2016 main rain season. It aimed at estimating associations among yields and yield contributing traits of 105 potato genotypes comprised five standard checks. Augmented design was used and data were collected for 20 traits. Marketable and total tuber yield ranged from 10.8 to 39.0 and 13.9 to 41.8 t ha^{-1}, respectively. Total tuber yield was significantly positively correlated with leaf area, tuber number per plant, tuber yield per plant, marketable tuber yield, bulking rate, large size tubers percentage and average tuber weight. In tuber quality parameters (tuber dry matter, specific gravity and total starch content) there were highly significant and positive genotypic correlation among them and also they were positively correlated in phenotype. Thus, potato tuber yield enhancement may be possible through indirect selection of positively correlated traits simultaneously.

Keywords: Augmented design, Correlation, traits, potato

INTRODUCTION

Among African countries, Ethiopia has possibly the greatest potential for the production of potato (*Solanum tuberosum* L.). About 70% of its arable land found above 1500 m is believed to be suitable for potato production (Medhin *et al*., 2000). As a result of this, the production of potato is expanding in Ethiopia at a faster rate than of other food crops. In Ethiopia, potato grown in four major areas: the central, the eastern, the north-western and the southern, out of which north-western areas of potato production is situated in Amhara region with 40% of the total coverage from the country (CSA 2008/2009). The productivity of potential potato growing zones in Meher (north-western area of Ethiopia): N/Gondar, W/Gojam, E/Gojam, S/ Gondar and Awi ranges 12.9 - 18.3 t ha^{-1} which is very low as compared to the potential yield (40 t ha^{-1}) obtained under research conditions (Abebe and Mela, 2000).

Drought stress is one of the most adverse factors to plant growth and productivity (Levy *et al*., 2006, Shao *et al*., 2008). Of the total arable land in Ethiopia, more than 60% is classified as semi-arid and arid (Reddy and Georgis, 1994). Moisture stress is the major problem in these areas which are characterized by inadequate and erratic or uneven rainfall distribution. Hence, developing drought tolerant varieties will make a significant contribution to increase crop production in the drought prone areas of Ethiopia.

The agro-ecology of the study area is characterized by erratic rainfall with short duration and high intensity (late onset and early cessation or termination) of rains (USAID, 2015). Thus, the amount, and distribution of rainfall play major role in

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drought occurrence. Global climate change seems to aggravate this problem. The production of potato in Simada Woreda is limited by a short growing period and will be contributed a lot to food and nutritional security if the right variety that can best fit to this environment. Currently, the National Potato Research Program reshaped its variety development program towards the development of drought tolerant potato varieties recognizing the absence of such varieties that can address the major production constraint facing drought prone areas in the country.

Yield is the outcome of complex interaction of several traits and environment. Proper understanding of association of different traits provides more reliable criterion for selection program to achieve its goal for high yield (Mohammad *et al.*, 2001). The primary interest in crop improvement is obtaining high yield that is not attainable by selection of genotypes only for yield rather through other traits. This requires proper understanding of the magnitude of correlations among various yield traits (Tadesse *et al.,* 2009). It has been pointed out that desirable phenotypic traits must be genetically associated with yield under stress, highly heritable, genetically variable, easy to measure, stable within the measurement period, and must not be associated with a yield penalty under unstressed conditions (Okogbenin *et al*., 2013). Development of new varieties depends on the knowledge of genetic variability of available populations. The success of selection of high yielding genotypes does also requires knowledge of association between yield and yield affecting traits. Hence, the objective of the study was to estimate the degree of association among tuber yield and yield related traits.

MATERIALS AND METHODS

Description of the experimental site: Field experiment was conducted at Adet Agricultural Research Center Simada research site in 2016 main growing season. The site is located in Amhara National Regional State in South Gondar Administrative Zone, 770 km North of Addis Ababa and 105 km South East of Debrtabor. Global position of the site is 11°21′N latitude and 38°25′E longitude and at an altitude of 2407 meter above sea level (Fig. 1). It has annual mean temperature of 16.8°C and monthly mean temperature ranges from 10.3°C -23.3°C. The site obtains 839 mm mean annual rainfall (Table 1) which

Table 1. Mean monthly weather condition of the experimental site in 2016.

S. No	Month	Rainfall (mm)	Maximum Temperature(°C)	Minimum Temperature (°C)
1	Jan	0.0	25	NA
2	Feb	0.0	27	NA
3	Mar	17.8	28.2	12
4	Apr	43.7	26.9	11.8
5	May	129.2	24.3	11.8
6	Jun	108	24.2	10.7
7	Jul	291.3	20.2	10.5
8	Aug	205.1	20.4	10.4
9	Sep	43.6	13.5	4.9
	Total	838.7		

Source: Ethiopian Meteorological Agency, Bahir Dar branch. NA=not available

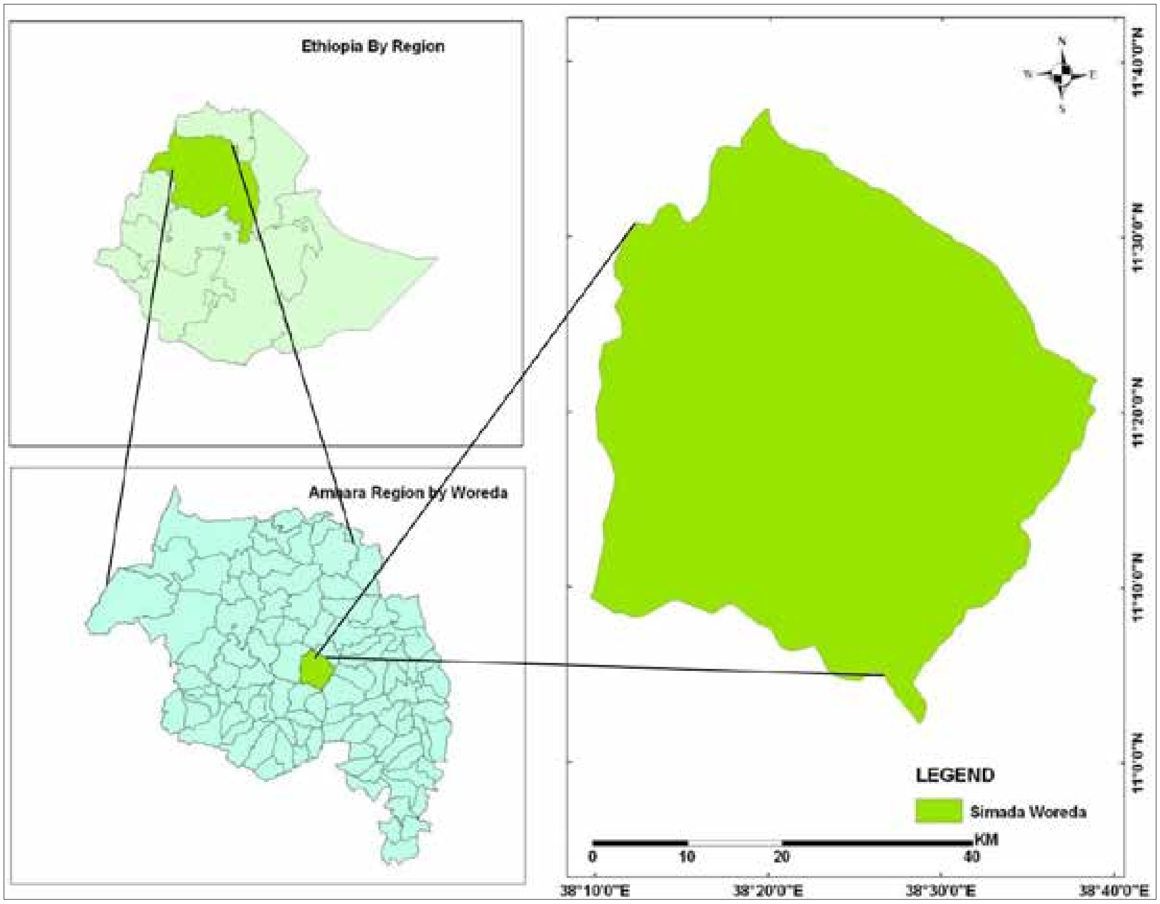

Figure 1. Map of the study area

is sufficient for potato production unless its distribution is erratic.

Treatments and experimental design: The experiment comprised 100 potato genotypes developed for moisture stress (drought prone) areas of the world by International Potato Center (CIP). The genotypes were introduced by the Adet Agricultural Research Center. Four released potato varieties in the country and one farmer's cultivar commonly used in Simada district were also included in the trial. The seed tubers for all the genotypes were collected from the Adet Agricultural Research Center (Table 2). The field trial was arranged in Augmented block design with 5 blocks. Each block contained 20 genotypes plus 5 checks.

The genotypes were not replicated, while the checks were replicated at each block. Tewenty genotypes randomly assigned to each block and then the genotypes plus checks were randomized to each experimental plot separately in a block. Each genotype was planted in a gross plot size of 2.25 m^2 (0.75 m × 3 m) which accommodate 10 plants. Two plants at the beginning and end of each row were considered as boarder plants. Eight plants in the middle were harvested with a net plot size of 1.8 m^2 (0.75 m × 2.4 m). The distance between plots and blocks were 1 and 1.5 m, respectively.

Experimental procedures and field management: Well-sprouted potato seed tuber having 35-45 mm diameter grouped

Table 2: List of accession used in the experiment

No.	Accession code	No.	Accession Code	No.	Accession code	No.	Accession code
1	16SET5.1	27	11SET3.4	53	19SET7.2	79	F16.3
2	16SET5.2	28	11SET3.5	54	19SET7.3	80	F26.1
3	16SET5.3	29	11SET3.6	55	19SET7.4	81	F26.2
4	16SET5.4	30	11SET3.7	56	5SET6.1	82	F29.1
5	16SET5.5	31	11SET3.8	57	5SET6.2	83	F29.2
6	16SET5.6	32	25SET6.1	58	5SET6.3	84	F29.3
7	16SET5.7	33	25SET6.2	59	5SET6.4	85	F10.1
8	16SET5.8	34	25SET6.3	60	5SET6.5	86	F10.2
9	16SET5.9	35	25SET6.4	61	2SET8.1	87	F14.1
10	16SET5.10	36	25SET6.5	62	2SET8.2	88	F14.2
11	16SET5.11	37	25SET6.6	63	2SET8.3	89	F14.3
12	16SET5.12	38	22SET7.1	64	3SET6.1	90	F22.1
13	20SET4.1	39	22SET7.2	65	3SET6.2	91	F22.2
14	20SET4.2	40	22SET7.3	66	23SET3.1	92	28SET6.1
15	20SET4.3	41	22SET7.4	67	23SET3.2	93	28SET6.2
16	20SET4.4	42	22SET7.5	68	4SET8.1	94	F18
17	20SET4.5	43	24SET5.1	69	4SET8.2	95	F20
18	20SET4.6	44	24SET5.2	70	4SET8.3	96	F28
19	20SET4.7	45	24SET5.3	71	27SET7.1	97	F23
20	20SET4.8	46	24SET5.4	72	27SET7.2	98	F24
21	20SET4.9	47	24SET5.5	73	F30.1	99	F15
22	20SET4.10	48	24SET5.6	74	F30.2	100	F21.1
23	20SET4.11	49	24SET5.7	75	F30.3	101	Belete (check)
24	11SET3.1	50	24SET5.8	76	F30.4	102	Gera(check)
25	11SET3.2	51	24SET5.9	77	F 16.1	103	Shenkolla(check)
26	11SET3.3	52	19SET7.1	78	F16.2	104	Guassa (check)
						105	Local (check)

under medium size were planted at a spacing of 75 and 30 cm between rows and plants, respectively, as per the national recommendation. Fertilizer was applied at the rate of 69 kg ha^{-1} P_2O_5 in the form of Di-amonium phosphate (150 kg ha^{-1} DAP) and 108 kg ha^{-1} N as urea (176 kg urea ha^{-1}) as per Adet Agricultural Research Center recommendation of the neighbouring zone Debretabor. All P was applied at planting while N was split-applied at 50% urea including N from DAP at the time of planting and the remaining 50% of the recommended rate was applied at 30 days after planting. Weeding, cultivation and earthing-up were practiced at the appropriate time to facilitate root, stolon and tuber growth as per the national recommendation for the crop. Two weeks prior to harvesting when the crop had attained maturity (yellowed stems with senescenced leaves) plants were dehullmed to harden the tuber skin.

Data collection: Phenological parameters (days to emergence, flowering and maturity) were collected from the entire plants in a row. Leaf area, plant height and stem number per plant were collected from five randomly taken plants in the center and the average value was considered. Tuber size distribution and other yield and yield components were measured from the net plot. The description of parameters and procedures of measurement are given below.

Days to emergence (DE): The numbers of days from planting to the emergence of 50% of the plants in each plot.

Days to flowering (DF): It was noted when 50% of the plants in each plot produced flowers.

Days to maturity (DM): Number of days from planting to when 90% of the plants in a plot attain physiological maturity.

Leaf Area (cm^2): To determine average leaf area of a leaf, five plants (hills) from each plot were randomly sampled and tagged. Individual leaf area of the targeted potato leaves were estimated from individual leaf length (top, middle and bottom parts of the plant and averaged) measured at 50% flowering (Firman and Allen, 1989). The leaf area of a leaf was determined by:

$$\text{Log10 (leaf area in cm}^2) = 2.06 \times \text{log10 (leaf length in cm)} - 0.458.$$

Plant height (cm): It was measured from the base of the stem to the tip of five randomly taken plants per plot and the average was used.

Stem number per plant/hill: The number of main stems per hill was counted from five randomly taken hills per plot at physiological maturity. Only the main stem i.e. those originating from the mother tuber was counted.

Tuber number per plant/hill: Total numberof tubers from the net plot was counted and divided by the number of harvested plants and registered as tubers number per hill.

Average tuber weight (g/tuber): The weight of total number tubers harvested from the net plot divided by the total number of tubers.

Tuber yield per plant (TYPP kg): The total weight of tubers harvested from net plot divided by the total number of harvested plants and the average weight of tubers was registered as tuber yield per plant.

Marketable tuber yield (t ha^{-1}): This refers to the tubers which were free from diseases, insect pests, physiological disorders, and that weighted greater than or equal to 20g. This was determined after harvest for each plot considering the planting space and calculated for total population per hectare (first it was determined per plot and then converted to ton ha^{-1}).

Unmarketable tuber yield (t ha^{-1}): This refers to tubers that had blemishes due to attack by pests, infection by diseases, deformed due to physiological disorder and that weighted less than 20g. It was first determined per plot and then converted to ton ha^{-1} for each treatment at harvest.

Total tuber yield (t ha^{-1}): The total weight of tubers that was harvested from entire harvestable plot was used to calculate total tuber yield tons ha^{-1}.

Bulking rate (g day^{-1}): Was calculated as total weight of tubers harvested from net plot divided by number of days taken from days to flowering to physiological maturity (CIP, 2014).

Tuber size distribution on weight basis: The tubers harvested from net plot were categorized in to very small (< 20g), small (20 to < 39 g), medium (39-75g), and large (>75 g) according to Lungaho *et al*. (2007). The proportion of the weight of each tuber category was expressed in percent.

Tuber dry matter content (%): Clean and unpeeled tubers were chopped into small 1-2 cm cubes and about 200 g chopped samples were dried in an oven at a temperature of 80^{O}C for about 72 hours to a constant weight at regular intervals. The percent of dry matter was calculated according to (CIP, 2007) as:

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

Specific gravity of tubers: Five kg of all size tubers were randomly taken from tubers used to estimate total tuber yield. Specific gravity was determined by the weight in air and weight in water method. The tubers first weighted in air and then submerged in water.

Where specific gravity = $\frac{\text{Weight in air}}{\text{Weight in air} - \text{Weight in water}}$ (Kleinkopf *et al.*, 1987).

Total starch content (g/100g): Starch content in percent was estimated from specific gravity as established by Talburt and Smith (1959) as cited by Yildrim and Tokuşoğlu (2005) as follows:

Starch content (%) = 17.546 + 199.07 × (specific gravity-1.0988), where specific gravity was determined as indicated above by the weight in air and weight in water method.

Data analysis: Analysis of variance was computed using the statistical package for augmented design (SPAD) software (Abhishek *et al.*, 2010). Significantly different means were separated using critical difference in each category viz., among control, among tests and tests vs control. Correlation coefficient among character were computed via SAS 9.0 software (SAS Institute Inc., Cary, USA).

Phenotypic and Genotypic correlation coefficient was computed as

$R_{pxy} = \frac{CovPxy}{\sqrt{\sigma^2 px * \sigma^2 py}}$ (Miller *et al.*, 1958)

Where, Rp_{xy} = phenotypic correlation coefficient between traits x and y

$Covp_{xy}$ = Phenotypic covariance between traits x and y

$\sigma^2 px$ = Phenotypic variance of trait x

$\sigma^2 py \sigma^2 py$ = Phenotypic variance of trait and

$R_{gxy} = \frac{Covgxy}{\sqrt{\sigma^2 gx * \sigma^2 gy}}$ (Miller *et al.*, 1958),

Where, rg_{xy} = Genotypic correlation coefficient between traits x and y

$Covg_{xy}$ = Genotypic covariance between traits x and y

σ^2_{gx} = genotypic variance for variable x

σ^2_{gy} = genotypic variance for variable y

RESULTS AND DISCUSSION

The ANOVA revealed highly significant (P<0.01) differences among genotypes for all traits except plant height, and small and medium size tubers (Table 3). In separate comparison of tests vs checks the analysis of variance indicated significant (P<0.05) differences for all traits except for unmarketable tuber yield and percentage of very small sizes. It also revealed significant (P<0.05) differences among controls (check varieties) for all traits except for plant height, average tuber weight, and small and large size tubers proportion. Significant differences were observed among tests (new entries) for all traits except for plant height, and small and medium size tubers. The significant differences among genotypes show the presence of adequate variations that allow applying selection breeding to obtain high yielding variety that combine other desirable traits.

In agreement with this result, Khayatnezhad *et al*. (2011) reported the significant differences among 10 potato genotypes for main stem per plant, tuber number per plant, average tuber weight, tuber yield per plant, tuber yield, dry matter content, starch content, and big tubers proportion as percentage. Fekadu *et al.* (2013) reported the presence of significant differences among nine regional and national released varieties for days to emergence, days to flowering, days to maturity, number of stem per plant, tuber number per plant, tuber

Table 3. Mean suqares and their significance for 17 traits of 105 potato genotypes evaluated at Simada during 2016.

	Sources of variation (degree of fredom)						
Traits	Block(4)	Treatment (104)	Among control (4)	Among tests (99)	Tests vs control (1)	Error	CV (%)
DE	1.36	6.67**	17.96**	5.29**	98.57**	0.76	5.64
DF	1.76	21.2**	33.56**	19.99**	90.74**	1.51	2.19
DM	51.24	44.62**	15.94*	41.25**	492.03**	3.49	2.02
LA	0.5	2.21**	2.69**	2.01*	19.11**	0.37	4.48
SNP	0.16	2.21**	1.86**	2.15**	9.21**	0.25	12.11
TNP	1.28	24.86**	10.05**	42.57**	61.99**	0.59	4.92
TYP	0.002	0.04**	0.015**	0.037**	0.04*	0.003	9.02
AVT	19.1	149.54**	24.53NS	152.46**	360.15**	12.75	9.18
MKY	6.97	27.94**	11.47*	28.72**	16.83*	2.57	6.76
UMY	0.04	1.9**	2.87**	1.86**	0.19NS	0.16	16.63
TY	6.66	27.08**	17.07**	27.55**	20.66**	2.12	5.56
BRP	1234.61	1264.29**	879.84**	1238.92**	5313.81**	107.91	7.79
VSP	74.51	137.5**	299.77**	132.06**	26.19NS	37.02	18.59
LTP	5.65	77.47**	11.71NS	80.87**	3.23NS	8.95	20.6
DMC	0.41	8.68**	2.72*	7.96**	103.73**	0.81	3.47
SG	0.00007	0.00081**	0.0004*	0.00074**	0.01**	0.00008	0.83
TSC	2.77	32.21**	14.04*	29.26**	396.61**	3.17	13.61

*and**=significant at $P<0.05$ and $P<0.01$, respectively. NS=Nonsignificant, DE= days to emergence, DF=days to 50% of plants flowering, DM=days to 90%maturity, LA=leaf area (cm^2), STN=stem number per plant, TNP=tuber number per plant, TYP=tuber yield per plant(kg), AVT=average tuber weight (gm), MKY=marketable tuber yield (ton ha^{-1}), UMK=unmarketable tuber yield (ton ha^{-1}), TY=Total tuber yield (ton ha^{-1}), BRP=bulking rate per plot(gm/day),VSP=very small size tubers percentage, LTP=large size tubers percentage, DMC=tuber dry matter content(%), SG=specific gravity of tuber, TSC= total starch content (gm/100gm), CV (%)= coefficient of variation in percent.

yield and big tubers proportion as percentage. Lamboro *et al.* (2014) found highly significant difference for all phenological traits, stem per plant, tuber yield, tuber per plant, and big tubers proportion as percentage. Mohammed and Burga (2015) evaluated 26 potato genotypes tolerant to heat stress at Dire Dawa and reported significant differences among genotypes for tuber yield, yield related traits and tuber dry matter content. Habtamu *et al.* (2016a) reported the existence of significant differences among 16 improved varieties and two farmers' cultivars evaluated for tuber yield and yield related traits at three locations of eastern Ethiopia.

Agronomic performance of Genotypes: Agronomic performance variation was noticed for all the traits among the genotypes which indicated that diverse genotypes were included in the study. This may provide sufficient scope for further selection and improvement on these traits. Days to emergence, days to flowering and days to physiological maturity ranged from 11.28 to 21.48, 39.68 to 64.08 and 74.04 to 106.64 days for 105 potato genotypes, respectively. In phenological traits 5, 71 and 77 new entries (genotypes) showed early emergence, flowering and maturity than the earliest released variety (Belete), respectively (Table 4).

Table 4. Mean and range of 17 agronomic traits of 105 potato genotypes at Simada in 2016.

Traits	Range	Mean	SE
DE	11.28-21.48	15.46	0.87
DF	39.68-64.08	55.97	1.23
DM	74.04-106.64	92.27	1.87
LA	10.04-18.56	13.55	0.61
SNP	1.67-9.23	4.18	0.51
TNP	7.05-38.97	15.67	0.77
TYP	0.19-1.02	0.6	0.05
AVT	16.36-69.62	38.9	3.57
MKY	10.81-38.99	23.7	1.6
UMY	0.65-9.41	2.45	0.41
TY	13.92-41.79	26.16	1.46
BRP	49.58-260.63	133.26	10.38
VSP	9.76-60.54	32.73	6.08
LTP	0.17-40.59	14.52	2.99
DMC	18.62-31.28	26.05	0.9
SG	1.02-1.15	1.07	0.009
TSC	1.14-27.19	13.09	1.78

DE= days to emergence, DF=days to 50% of plants flower, DM=days to 90%maturity, LA=leaf area (cm^2), STN=stem number per plant, TNP=tuber number per plant, TYP=tuber yield per plant(kg), AVT=average tuber weight(gm), MKY=marketable tuber yield (ton ha^{-1}), UMK=unmarketable tuber yield (ton ha^{-1}), TY=Total tuber yield (ton ha^{-1}), BRP=bulking rate per plot(gm/day),VSP=very small size tubers percentage, LTP=large size tubers percentage, DMC=tuber dry matter content(%), SG=specific gravity of tuber, TSC= total starch content (gm/100gm), and SE = standard error.

The genotypes also revealed variations for leaf area and stem number per plant that ranged from 10.06 to 18.56 cm^2, and 1.67 to 9.23, respectively. The bulking rate of genotypes ranged from 49.58 to 260.63gm day $^{-1}$ while tuber number per plant, tuber yield per plant and average tuber weight ranged from 7.05 to 38.97, 0.19 to 1.02 kg and 16.36 to 69.62gm, respectively. Marketable, unmarketable and total tuber yield of genotypes ranged from 10.81 to 38.99, 0.65 to 9.41 and 13.92 to 41.79 t ha^{-1}, respectively. The three new entries viz. 20SET4.2, 20SET4.1, and 16SET5.5, which were introduced as drought tolerant genotypes had total tuber yield potential of 41.8, 39.1 and 37.5 respectively, while the best check (Belete) gave 27.7 t ha^{-1}. In tuber size distribution the genotypes had wide range of variation in which ranged from 9.76 to 60.54 for very small size tubers proportion, while it ranged from 0.17 to 40.59% for large size tubers proportion.

In line with this finding, Sattar *et al*. (2007) obtained wide range of variation in plant height, days to maturity, tuber yield, stem per plant, and days to emergence in potato genotypes in Bangladesh. Fekadu *et al*. (2013) observed wide range of variations among potato genotypes for tuber number per plant, big size tubers proportion as percentage, days to flowering, days to 90% physiological maturity, number of stems per plant, and tuber yield per plant. Mohammed and Simret (2015) reported wide range of variations among 26 potato genotypes for total tuber yield, marketable and unmarketable tuber yield, tuber dry matter and starch content evaluated at lowland area in Dire Dawa. Habtamu *et al*. (2016a) reported variations among 18 potato cultivars for total tuber yield, marketable tuber yield, unmarketable tuber yield, average tuber weight and large tuber number as percent at three locations of eastern Ethiopia. Habtamu *et al*. (2016b) also stated variations among 18 potato cultivars for tuber quality parameters, viz, tuber dry matter, specific gravity and total starch content.

Genotypic and Phenotypic Correlation of total tuber yield with other characters: Estimation of genotypic and phenotypic correlation coefficients between each pair of the studied traits are presented in Table 5. Tuber yield showed positive and significant genotypic correlation with most of the traits except with days to emergence, days to flowering, dry matter content, and very small size tubers percentage. Average tuber

Table 5. Phynotypic above and genotypic below diagonal Correlation coefficients for 17 yiueld and yiled component traits of 105 potato genotypes evaluated at Simada 2016.

Variable	DE	DF	DM	LA	STN	TNP	TYP	AVT	MKY	UMY	TY	BRP	VSP	LTP	DMC	SG	TSC
DE		0.10	-0.19	-0.24	-0.03	-0.05	0.07	0.10	0.23	0.08	0.25	-0.02	0.10	0.3	-0.013	0.13	0.13
DF	0.23		-0.23	0.19	0.07	-0.25	0.29	0.15	0.02	-0.15	-0.01	0.12	-0.28	0.22	-0.38	-0.02	-0.02
DM	0.06	0.38**		-0.15	0.08	0.4	-0.07	-0.29	-0.40	-0.18	0.47*	-0.01	0.18	-0.09	-0.07	0.08	0.09
LA	0.07	0.12	0.27		-0.24	0.29	0.29	0.63*	0.22	-0.03	0.23	0.35	-0.35	0.48	-0.11	-0.003	-0.02
STN	-0.27	-0.21	-0.29	-0.44		0.27	0.25	-0.37	-0.01	0.02	-0.008	0.39	0.38	0.48*	-0.18	-0.27	-0.29
TNP	-0.16	-0.14	-0.028	-0.03	0.39**		0.5*	0.029	0.05	-0.19	0.02	0.37	0.2	0.08	0.08	0.24	0.22
TYP	-0.06	-0.24*	0.03	0.21*	0.14	0.31**		0.25	0.27	-0.23	0.24	0.41	-0.08	0.32	-0.21	0.08	0.05
AVT	0.21*	0.005	0.02	0.18	-0.31**	-0.57	0.45**		0.36	0.11	0.42	0.02	-0.35	0.82**	-0.14	0.06	0.012
MKY	-0.04	-0.18	0.05	0.21*	0.05	0.11	0.85	0.53**		-0.40	0.98**	0.21	-0.57**	0.40	-0.103	-0.27	-0.206
UMKY	-0.07	0.05	0.08	0.13	0.11	0.72**	0.09	-0.49**	-0.19		-0.21	0.002	0.46	-0.14	0.27	0.36	0.31
TY	-0.064	-0.18	0.07	0.25*	0.08	0.29**	0.88**	0.41**	0.97**	0.07		0.22	-0.51*	0.39	-0.05	-0.22	-0.15
BRP	-0.007	-0.02	-0.48	0.07	0.13	0.11	0.52**	0.29**	0.52**	-0.11	0.49**		-0.05	-0.034	-0.26	-0.28	-0.29
VSP	-0.13	0.10	-0.01	-0.02	0.09	0.52**	-0.36**	-0.7	-0.49	0.75**	-0.31**	-0.34**		-0.39	0.07	0.34	0.27
LT	0.11	-0.05	0.17	0.2*	-0.32**	-0.51**	0.41**	0.83**	0.48**	-0.47**	0.37**	0.2*	-0.65**		-0.16	0.25	0.22
DMC	-0.11	0.23*	0.46**	0.004	0.01	0.12	-0.05	-0.17	-0.05	0.03	-0.05	-0.36**	0.01	-0.17		0.54*	0.55
SG	-0.2*	0.13	0.34**	0.034	0.002	0.02	0.01	-0.08	0.03	-0.03	0.02	-0.24*	-0.08	-0.09	0.81**		0.98**
STC	-0.21*	0.12	0.34**	0.03	0.01	0.02	-0.003	-0.09	0.02	-0.03	0.01	-0.25*	-0.06	-0.11	0.82**	0.99**	

*and**=indicate significance at 0.05 and 0.01 probability levels, respectively, DE= days to emergence, DF=days to 50% of plants flower, DM=days to 90%maturity, LA=leaf area (cm^2), STN=stem number per plant, TNP=tuber number per plant, TYP=tuber yield per plant(kg), AVT=average tuber weight(gm), MKY=marketable tuber yield (ton ha^{-1}) UMK=unmarketable tuber yield (ton ha^{-1}), TY=Total tuber yield (ton ha^{-1}), BRP=bulking rate per plot(gm/day),VSP=very small size tubers percentage, LTP=large size tubers percentage, DMC=tuber dry matter content(%), SG=specific gravity of tuber, TSC= total starch content (gm/100gm).

weight, tuber number per plant, tuber yield per plant, marketable tuber yield, bulking rate per plot, and large size tubers percentage had highly significant and positive genotypic correlation with total tuber yield. It had also significant positive correlation with leaf area. Total tuber yield also revealed positive and significant phenotypic correlation with days to maturity and marketable tuber yield. In addition, total tuber yield had positive correlation with most of the traits like days to emergency, leaf area, tuber yield per plant, average tuber per plant, bulking rate per plot and large tuber percentage. Positive correlation indicating that selection for high mean values of genotypes for these traits will simultaneously increase the total tuber yield.

In agreement with this result, Verma and Singh (2016) stated as correlation matrix of strong positive highly significant correlation of tuber yield with average tuber weight, tuber yield per plant and marketable yield per plot. Khayatnezhad *et al*. (2011) obtained significant correlation between tuber yield with stem per plant, tuber number per plant, average tuber weight, tuber weight per plant and big tuber percentage. Sattar *et al*. (2007) found positive correlation of tuber yield with tuber number per plant, compound leaves per plant in number and average tuber weight. Fekadu *et al.* (2013) reported positive significant phenotypic correlation of tuber yield with big tubers percentage, days to flowering and days to maturity. Ummyiah *et* *al.* (2013) studied genotypic and phenotypic correlations and reported that tuber yield per plant had positive and significant phenotypic correlation with number of stems per hill, leaf area, number of stolons per plant, number of tubers per plant, average tuber weight, and tuber yield per hectare. Lamboro *et al.* (2014) also reported significant positive association of tuber yield with stem number per plant and medium tuber percentage, and Singh *et al.* (2015) found positive association between number of tubers per plant and total tuber yield. Hence, direct selection for these traits may be helpful for development of high yielding potato genotypes.

Tuber yield had highly significant and negative genotypic correlation with proportion of very small tubers percentage, but weak nonsignificant and negative association with days to emergence, days to flowering, and tuber dry matter content. Similarly total tuber yield had negative phenotypic correlation with unmarketable tuber yield, very small tuber percentage and specific gravity with non significant and significant level, respectively. It had also weak negative correlation with days to flowering, stem number per plant, dry matter content and total starch content of the tuber in percentage. The negative association of yield with these traits suggested that the selection of genotypes with high mean values for the traits might lead to low yield of genotypes. Lamboro *et al.* (2014) reported weak correlation of tuber yield with days to emergence and flowering.

Fekadu *et al.* (2013) also found negative correlation of tuber yield with days to emergence. Selection based on the performance of yield, which is controlled by many genes that make it a complex trait, is usually not very efficient (Sastri, 1974). Yield is dependent on a number of yield component traits; therefore, knowledge of association of different components together with their relative contributions has immense value in selection. Therefore, it is necessary to consider traits that showed strong positive association with yield as simultaneously increase the total tuber yield while, selection of traits that exhibited strong negative association with yield may result low mean value of total tuber yield.

Correlation among other characters: Phenological traits had positive genotypic correlation among themselves in which days to maturity correlated positively and highly significant with days to flowering and positive to days to emergence. The positive correlation indicates simultaneous improvement of these traits is possible. However, it had negative genotypic association with stem number per plant,bulking rate per plot,tuber number per plant and very small tuber size percentage and also days to maturity had negative phenotypic correlation with days to emergency and flowering.

Leaf area had positive and significant genotypic correlation with tuber yield per plant, marketable tuber weight, and large size tubers percentage and also it had positive phenotypic correlation with tuber number per plant, tuber yield per plant, average tuber weight, marketable tuber yield, bulking rate per plot and large tuber percentage but leaf area had negative genotypic correlation with stem number per plant and negative phenotypic correlation with days to emergency, days to maturity, stem number per plant, very small tuber percentage and dry matter content.

Tuber yield per plant revealed significant and positive genotypic correlation with tuber number per plant, average tuber weight, bulking rate and large size tubers percentage and it had strong positive correlation with marketable tuber yield. Tuber yield per plant also had positive phenotypic correlation with tuber number per plant, average tuber weight, marketabale tuber weight, bulking rate and large tuber percentage. On the other hand, negative and significant genotypic correlation were found with days to flowering and very small tuber percentage. Similarly tuber yield per plant had negative correlation with unmarketable tuber yield and dry matter content. Stem number per plant and average tuber weight revealed signifivant negative genotypic correlation.

Highly significant and positive genotypic correlation revealed from marketable tuber yield with average tuber weight, bulking rate and large tuber percentage, similarly average tuber weight correlated with bulking rate per plot and large tuber percentage. In phenotypic marketable tuber yield also positively correlated with days to emergence, average tuber weight, bulking rate and large tuber percentage.

Unmarketable tuber yield had highly significant and strong genotypic correlation with tuber number per plant and very small tuber percentage. Marketable tuber yield had weak negative correlation with days to emergency, days to flowering, unmarketable tuber yield, dry matter content and very small tuber percentage and also weak positive correlation with days tp maturity, stem number per plant, tuber number per plant, specific garvaity and total starch content. Marketable tuber yield had negative phenotypic correlation with days to maturity, unmarketable tuber yield, very small tuber percentage, dry matter content, specific gravity and total starch content. Unmarketable tuber yield had significant negative genotypic correlation with average tuber weight and large tuber percentage. These positive and significant correlation of pairs of traits indicate the possibility of simultaneous improvement of the traits, while the negative correlations prohibit the simultaneous improvement of those traits.

Sattar *et al.* (2007) reported positive and significant correlation of tuber yield per plant with average tuber weight, tuber number per plant and tuber number per plant with average tuber weight. Singh (2008) reported that number of tubers per plant and weight of tubers per plant had significant and positive correlation with marketable tuber weight.

Tuber size distribution had negative genotypic and phenotypic correlation among them (very small size tubers with large size tubers percentage). The proportion of very small size tubers in percent showed negative genotypic and phenotypic correlation with tuber yield per plant, average tuber weight, and marketable tuber yield, but positively and significant correlated with unmarketable tuber yield and tuber number per plant.

Tuber quality parameters (tuber dry matter, specific gravity and total starch content) had strong and positive genotypic association among them and also they had positive phenotypic correlation. Hence, simultaneous improvement of these quality governing traits is possible. Gray and Hughes (1978) as cited by Abebe *et al*. (2012) reported that starch constitutes 65–80% of the dry matter content of the potato tuber. In addition, tuber dry matter, specific gravity and total starch content had positive and significant correlation with days to maturity. This is because of the accumulation of starch through time. In agreement with the current study results, Khayatnezhad *et al.* (2011) found positive and significant correlations between starch content and dry matter content. Abebe *et al*. (2012) reported the presence of a strong and positive association between dry matter content and starch content and also tubers from relatively long varieties had higher dry matter content than tubers of early-maturing varieties.

Kalloo (1988) stated as if any component of yield is positive correlation between, then there may be the possibility to increase total yield by selecting a particular component. Those characters with non-significant correlation with each other indicated the independent nature of character in relation to the other. Rangaswamy (1995) stated as negative correlation between two traits implying selection for improving one trait will likely cause decrease in the other trait whereas for positive correlation, simultaneous improvements of both traits might be achieved. Ingeneral almost all yield and its contributing characters the genotypic correlation coefficients were higher than corresponding phenotypic correlation coefficients, this implies the traits express their potential due to genetic reason rather than the environmental effect thus phenotypic selection might be satisfying.

CONCLUSION

Understanding correlation of quantitative characters, especially the yield and its attributes and amongthem provides an idea of correlation that could be effectively utilized in selecting the desired characters in segregating population. In conclusion most of the triats had positive genotypic and phenotypic correlation to tuber yield and among them, as a result of this considering these tarits for further breeding facilitate efficient potato improvement program.

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CONFLICT OF INTEREST

The authors declared no conflict of interest

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