Journal of Genetics, Genomics & Plant Breeding 3(4) 9-22 (October, 2019)
ISSN (Online): 2581-3293

RESEARCH ARTICLE

Association between traits in potato for the assessment of drought tolerance under moisture deficit areas of North Western Ethiopia

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Manuscript received: June 7, 2019; Decision on manuscript: July, 5, 2019; Manuscript accepted: September 15, 2019

Abstract

Understanding correlation of different traits provides more reliable criterion for selection program to achieve its goal for high yield. Hence, estimation of traits correlation is pivotal in the process of variety development. The experiment conducted at Adet Agricultural Research Center, Simada a satellite site for drought experiments, in 2016 main rain season to estimate association among yield and yield affecting traits of 105 potato genotypes comprised five checks. Augmented design was used and data were collected for 20 traits. The analysis of variance revealed the presence of highly significant (P<0.01) differences among genotypes for all traits except plant height and small and medium size tubers percentage. Marketable and total tuber yield ranged from 10.81 to 38.99 and 13.92 to 41.79 ton ha^{-1}, respectively. The highest total tuber yield recorded by genotype 20SET4.2 (41.8 ton $^{-1}$ha) followed by 20SET4.1 (39.1) 16SET5.5 (37.5) while the best check (Belete) gave 27.7ton $^{-1}$ha. Total tuber yield showed significant and positive correlation with leaf area, tuber number per plant, tuber yield per plant, marketable tuber yield, bulking rate, large size tubers percentage and average tuber weight, but significant negative correlation was observed with very small tuber percentage. 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 Thus, selection for positively correlated traits will simultaneously increase the total tuber yield of potato.

Key words: Augmented design, correlation, potato

Introduction

Among African countries, Ethiopia has possibly the greatest potential for potato production; since 70% of its arable land found above 1500m is believed to be suitable for potato production (Gebremedhin *et. al*., 2000). As a result of this, the production of potato is expanding at a faster rate than other food crops in Ethiopia. In Ethiopia, potato grown in four major areas: the central, the eastern, the north-western and the southern in which north-western areas of potato production is situated in Amhara region with 40% of the total coverage from the national (CSA 2008-2009). The productivity of potential potato growing zones in meher (north-western): N/Gondar, W/Gojam, E/Gojam, S/Gondar and Awi range 12.9- 18.3 tons/ha which is very low as compared to the potential yield (40 t ha^{-1}) obtained under research conditions (Getachew and Mela, 2000). Moisture stress due to recurrent drought have been found one of the contribute to the low yield of potato (Doss *et. al*., 2008; FAO, 2010).

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 of Ethiopia, more than 60% is classified as semi-arid and arid agro-ecology zones (Reddy and Kidane, 1991). 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 have a significant contribution to increase crop production in moisture stress areas of Ethiopia. Agro-ecology of the study area is characterized by erratic rainfall pattern with short duration and high intensity (late onset and early cessation or termination of rain) (USAID, 2015). This implies that besides the amount, distribution of rainfall has sizeable role for drought occurrence. The prevailing global climate change aggravates this problem from time to time. The production of potato in Simada Woreda is limited by this short length of growing period and contributes a lot to food and nutritional security if the right variety that can best fit to this environment is in place. This is a common production problem facing all drought prone areas of the country owing to the earlier national potato improvement strategy which mainly focused on selection high yielding and disease resistant varieties, particularly of late blight for optimum moisture agro-ecologies in the country. 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 (Tadele *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 require 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 executed 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 $11^0$21'N latitude and $38^0$25'E longitude and at an altitude of 2407 m.a.s.l. It has annual mean temperature of 16.8°C and monthly mean temperature ranges from 10.3°C -23.3°C. The site obtains 838.7mm mean annual rainfall which is abundant enough but erratic distribution.

Treatments and experimental design

The experiment comprised 100 potato genotypes tailored for moisture stress (drought prone) areas of the world by International Potato Center (CIP). The genotypes were introduced by Adet

Agricultural Research Center from where seed tubers for all the genotypes were collected. Four released potato varieties in the country and one farmer's cultivar commonly used in Simada district were also included in the trial. The lists of accession and checks are given in Table 1. The field trial was arranged in augmented block design with 5 blocks. Each block contained 20 genotypes plus 5 checks.

Table1: 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	104 105	Guassa(check) Local(check)

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 $2.25m^2$ (0.75 m x 3 m) which accommodate 10 plants. The two plants at the beginning and end of each row were considered as boarder plants. Eight plants in the middle were harvestable plants with net plot size of 1.8 m^2. The distance between plots and blocks were maintained at1 and 1.5 m, respectively.

Experimental procedures and field management

Well-sprouted potato seed tuber having 35-45 mm diameter grouped under medium size were planted at 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 DAP (150kg ha^{-1} DAP) and 108 kg ha^{-1} N in the form of Urea (176kg Urea ha^{-1} + from 150kg ha^{-1} DAP) as per Adet Agricultural Research Center recommendation of the neighbouring zone Debrtabor. The whole rate of phosphorus was applied during planting while nitrogen fertilizer was applied in split application of 50% Urea (46% N) including nitrogen from days after planting at the time of planting and the remaining 50% of the recommended rate was applied 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. Before two weeks of harvesting when the crop attained maturity (yellowed stems with senescence leaves) the plants were dehullmed to harden the tubers skin.

Data collection

Data was collected on the basis of plot, net plot and sample plants from plants in the center of a row. 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): 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 as: Log10 (leaf area in cm^2) = 2.06 x log10 (leaf length in cm) - 0.458.

Plant height (cm): 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 number of tubers from the net plot were 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 per ha).

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 per ha 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: 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 Lung'aho *et al*. (2007). The proportion of the weight of each tuber category was expressed in percentage.

Tuber dry matter content (%): Clean and unpeeled tubers were chopped into small 1-2 cm cubes and about 200g 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:

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

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. Tubers first weighted in air and then weighted 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 by using 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 was done via SAS statistical software package, version 9.0.

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

$\sigma^2 py$ = 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

Analysis of variance (ANOVA) of 17 quantitative traits for the 105 potato genotypes is presented in Table 2. The analysis of variance revealed the presence of highly significant (P<0.01) differences among genotypes for all traits except plant height, and small and medium size tubers. In separate comparison of tests vs checks the analysis of variance showed significant (P<0.05) differences for all the traits except for unmarketable tuber yield and very small size tuber percent. 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. Addisu *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 yield and big tubers proportion as percentage. Abraham *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. Wassu and Simret (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.

Table 2: Mean squares and their significance for 17 traits of 105 potato genotypes

	Sources of variation (degree of freedom)						
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,

Where, 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.

Agronomic performance of genotypes

Agronomic performance variation was noticed in 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 3.

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 ton 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 ton $^{-1}$ ha. 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. Addisu *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. Wassu 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 reported good amount of variability among 18 potato cultivars for tuber quality parameters, *viz.*, tuber dry matter, specific gravity and total starch content.

Table 3: Mean and range of 17 agronomic traits of 105 potato genotypes

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	0.60	0.05
AVT	16.36-69.62	38.9	3.57
MKY	10.81-38.99	23.7	1.60
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	0.99
SG	1.02-1.15	1.07	0.009
TSC	1.14-27.19	13.09	1.78

Where, 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.

Correlation of traits

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 is presented in Table 4. 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 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 implies that selection for high mean values of genotypes for the traits will simultaneously increase the total tuber yield.

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) reported positive correlation of tuber yield with tuber number per plant, compound leaves per plant. Addisu *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 stolon per plant, number of tubers per plant, average tuber weight, and tuber yield per hectare. Abraham *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 non-significant 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. Abraham *et. al*., (2014) reported weak correlation of tuber yield with days to emergence and flowering.

Addisu *et al.* (2013) 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, marketable tuber weight, bulking rate and large tuber percentage. On the other hand, negative and significant genotypic correlations were found with days to flowering and very small tuber percentage. Similarly tuber yield per plant had negative correlation with tuber yield and dry matter content. Stem number per plant and tuber weight revealed significant negative correlation.

Highly significant and positive genotypic correlation revealed from 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 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. Tuber yield had negative correlation with days to emergency, unmarketable tuber yield, dry matter content and very small tuber percentage and also weak positive correlation with days to maturity, stem number per plant, tuber number per plant, specific gravity 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 and total starch content. Unmarketable tuber yield had significant negative genotypic correlation with average tuber weight and large tuber percentage. Positive and significant correlation of traits indicates 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. Singh (2008) reported number of tubers per plant and weight of tubers per plant had significant and positive correlation with tuber weight. Tuber size had negative genotypic and phenotypic correlation among them. 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 positive genotypic association also had positive phenotypic correlation hence, simultaneous improvement of these quality governing traits is possible. Tesfaye *et. al*., (2012) reported 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. Tesfaye *et al*. (2012) reported the presence of a strong and positive association between dry matter content and starch content. Also reported tubers from relatively long varieties had higher dry matter content than tubers of early-maturing varieties. Kalloo (1988) reported any component of yield showing positive correlation, 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) noted negative correlation between two traits implying selection for improving one trait will likely cause decrease in the other trait, simultaneous improvements of both traits might be achieved.

In general for almost all yield and its contributing characters the genotypic correlation coefficients were higher than phenotypic correlation coefficients. Nandpuri *et. al*., (1973), showed higher genotypic correlations than phenotypic might be due to modifying or masking effect of environment in the expression of these characters under study.

Journal of Genetics, Genomics & Plant Breeding **3(4) 9-22 (October, 2019)**
ISSN (Online): 2581-3293

Table 4: Phynotypic and genotypic correlation coefficients for 17 yield and yield component traits of 105 potato genotypes

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	-0.20
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).

Conclusion

Analysis of variance revealed the presence of highly significant differences among genotypes for all traits except plant height, small and medium size tubers. Moreover, statistically significant differences among tests (new entries) were also observed for all traits except for plant height, small and medium size tubers. The genotypes had wide range of variations for 17 out of 20 traits. More importantly, the variations among genotypes were large for marketable, unmarketable and total tuber yield of genotypes and ranged from 10.81 to 38.99, 0.65 to 9.41 and 13.92 to 41.79 ton ha^{-1}, respectively.

Total tuber yield showed positive genotypic and phenotypic correlation with most of the traits, tells that selection for high mean values of genotypes for these traits will simultaneously increase the total tuber yield. 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 Thus, selection for positively correlated traits will simultaneously increase the total tuber yield of potato. On the other hand tuber yield had negative genotypic correlation with proportion of very small tubers percentage, 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, days to flowering, stem number per plant, dry matter content and total starch content of the tuber in percentage. This negative correlation indicating that the selection of genotypes with high mean values for the traits might lead to low yield of genotypes. 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 traits for further breeding facilitate the efficient potato improvment program.

Acknowledgments

We would like to acknowledge Amhara Agricultural Research Center (ARARI) and Adet Agricultural Research Center for financial support.

Conflict of interest

The authors declared no conflict of interest

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