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Genetic variability and association between agronomic characters in some potato (*Solanum tuberosum* L.) genotypes in SNNPRS, Ethiopia

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Thirteen (13) potato genotypes were evaluated for genetic variability and association of agronomic characters among themselves and tuber yield. The study aimed to find out the genetic variability, and interrelationships among different characters in potato. The plot design used for the experiment was a randomized complete block design with three replications. The analysis of variance showed that the mean square due to genotype were highly significant ($p<0.01$) for all characters studied, which indicates the existence of sufficient genetic variability and there was less coefficient of variation in all of the characters indicating good precision of the experiment. Genotypic correlation coefficient was found to be higher in magnitude than that of phenotypic correlation coefficients, which clearly indicated the presence of inherent association among various characters. Tuber yield was positively correlated with plant height, biological yield, harvest index and big tuber percentage at both the phenotypic and genotypic levels. In contrast, it was negatively correlated with small and medium tuber percentage at both levels. Path coefficient analysis at the phenotypic level revealed that days to flowering, plant height, tuber diameter, biological yield, harvest index and medium tuber percentage showed positive direct effects on tuber yield. The genotypic path analysis also indicated that biological yield and harvest index showed positive and significant correlation. Therefore, these characters are more important than other traits for the genetic improvement of potato.

Key words: Genetic variability, potato, heritability, correlation, path coefficient analysis.

INTRODUCTION

Potato *(Solanum tuberosum* L.*)* belonging to the family *Solanaceae*, is one of the most important food crops of Ethiopia as well as of many countries of the world. It produces more calories and protein per unit area with minimum time and water than most of the major food crops (Upadhya, 1995). It is cultivated worldwide under various environmental conditions. It can be found in both temperate and tropical regions from the sea level to 4000 m above sea level (Alberino et al., 2004). The amount of variability that exists in the germplasm collection of any crop is of the utmost importance towards breeding for better varieties. Particularly, genetic variability for a given character is a basic prerequisite for its improvement by systematic breeding (Engida et al., 2007). Potato cultivars are generally distinguished on the basis of morphological traits and have a wide variability of

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Table 1. Mean performance of 13 quantitative characters of the 13 potato genotypes at Lera, 2011.

Genotype	DE	DF	DM	PH	NS	TN	TY	TD	BY	HI	STP	MTP	BTP
Bule	20.5	58.5	108.5	79.6	6.6	11.8	1.43	4.93	1.576	0.90	21.3	35.5	43.5
Jalenie	21.5	64	112	99.0	9.7	16.0	1.49	4.39	1.841	0.81	13.7	35.6	49.5
Gera	23	70.5	116	89.8	3.8	10.4	1.28	4.87	1.474	0.87	4.6	29.8	65.7
Zemen	27	60.5	102	83.6	5.0	11.8	1.20	4.97	1.330	0.90	27.5	27.8	44.8
Merachare	28.5	68.5	114	80.2	5.0	12.3	0.96	4.74	1.745	0.55	31.9	41.4	26.8
Tolcha	27.5	63.5	105.5	50.1	5.2	10.1	0.89	3.99	0.950	0.93	26.2	35.9	38.4
Gabissa	26	69.5	115	70.1	5.0	15.2	1.42	5.26	1.545	0.92	27.9	36.6	35.6
Gudanie	21	62	108	84.1	4.0	16.4	1.76	4.49	1.924	0.91	25.0	39.4	35.7
Guassa	25	66.5	109.5	95.5	6.2	11.7	1.16	4.58	1.417	0.82	21.8	31.5	46.8
Mesno	23	62	97	93.8	5.0	24.4	0.97	4.08	1.135	0.85	48.1	46.2	5.8
Holbo	24	68.5	112.5	97.9	8.3	21.8	0.99	3.94	1.134	0.87	33.3	49.0	17.8
Sako	27	NE	98	26.7	6.9	16.1	0.66	3.57	0.674	0.98	55.8	43.8	0.5
Fako	29	66	116	63.9	4.5	11.8	0.95	4.13	1.024	0.93	57.4	34.8	7.9

DE= days to emergence; DF = days to flowering; DM = days to maturity; PH = plant height/cm/; NS = number of stem/plant; TD = tuber diameter/cm/; TY = tuber yield/kg/; TN=tubers number per plant; BY = biological yield/kg/; HI = harvest index; STP = small tuber percentage; MTP = medium tuber.

botanical characteristics. Phenotypic characterisation in potato is done by assessing variations in the flower, leaf and tuber characteristics (Huaman, 1991). Morphological characterization has been used for various purposes including identification of duplicates, studies of genetic diversity pattern and correlation with characteristics of agronomic importance (CIAT, 1993).

High yield with good quality is the most important objective in potato breeding. Tuber yield is a complex character associated with many interrelated components. Generally, a path coefficient analysis is needed to clarify relationships between characteristics, because correlation coefficients describe relationships in a simple manner. Path coefficient analysis shows the extent of direct and indirect effects of the causal components on the response component (Tuncturk and ÇiftÇi, 2005).

Ethiopia is known to have suitable edaphic and climatic conditions for the production of high quality seed potatoes. About 70% of the available agricultural land is located at an altitude of 1800-2500 m above sea level and receive an annual rainfall of more than 600 mm, which is suitable for potato production (Tsegaw, 2006). However, the national average tuber yield (8.33 tons per hectare) is very low compared to the world's average yield of 16.02 tons per hectare. The low acreage and yield are attributed to many factors, but lack of high-quality seed potatoes is the major factor (Gildemacher et al., 2009).

Southern Ethiopia, where potato is mainly grown, is located in the Southern Nations', Nationalities' and Peoples' Regional State (SNNPRS) and partly in the Oromiya region. The major potato producing zones in this area are Gurage, Gamo Goffa, Hadiya, Wolayta, Kambata, Siltie and Sidama in the SNNPRS and West Arsi zone in Oromiya. More than 30% of the total number of potato producing farmers in the country is located in this area (CSAE, 2008/9). The present study was undertaken in order to find out the genetic variability, interrelationships among different characters and the direct and indirect contributions of these characters towards tuber yield.

MATERIALS AND METHODS

The study was conducted in Southern Nations, Nationalities and People's Regional State, Siltie Zone, West Azernet Berbere Woreda, Lera Secondary School experimental field located at an altitude of 2635 m above sea level and longitude of 7°33′N 37°51′E , and 260 km south of Addis Ababa. It has an average annual rainfall of about 1300 mm and annual mean temperature of 17.5°C with mean minimum and maximum temperature of 16°C and 19°C, respectively. The experimental genotypes were planted on March 10, 2011.

Nine potato varieties (Jalenie, Gera, Gudanie, Zemen, Bule, Gabissa, Tolcha, Guassa and Merachare,), which were released by the regional and national research institutions at different times and four locally available potato varieties (Fako, Holbo, Mesno, Sako) were used. The sources of these varieties were Haramaya University Research Center, Holeta Agricultural Research Center and West Azernet Berbere Woreda Agricultural and Rural Development Office.

The experiment was arranged in a randomized complete block design with three replications. Each variety was planted on a 3 m long and 3 m wide plot consisting of four rows, which accommodate ten plants per row and thus 40 plants per plot. A distance of 1 m was maintained between the plots and the row to row spacing was 75 cm while plant to plant distance was 30 cm. The middle two rows were used for data collection. The observations were recorded for various characters viz. days to 50% emergence, days to 50% flowering, days to 90% maturity ,plant height(cm), stems per plant, tuber diameter(cm), tuber yield (kg), number of tuber per plant , biological yield(kg), harvest index, small tuber percentage , medium tuber percentage and big tuber percentage.

The mean performance of individual genotype was pooled and employed for statistical analysis (Table 1). Analysis of variance to test the significance for each character was carried out as per

Table 2. Mean squares from analysis of variance for the 13 characters of 13 potato genotypes evaluated at Lera, 2011.

Source of variation	d.f	Mean square												
		D E	D F	DM	PH	NS	TD	TY	TN	BY	HI	STP	MTP	BTP
Rep.	2	0.154	2.462	0.154	0.007	0.053	0.010	0.016	0.735	0.021	0.00	4.080	1.58	9.480
Genotype	12	16.78**	677.0**	84.55**	879.2**	5.79**	0.486**	0.016**	38.31**	0.27**	.023**	476 **	79.0**	752**
Error	12	1.154	15.54	21.846	0.623	0.137	0.009	0.006	0.161	0.006	.000	0.545	0.69	1.463
Grand Mean		24.85	60.00	108.77	78	5.76	4.45	1.162	14.586	1.37	0.86	30.32	37.5	32.19
CV(%)		4.3	1.9	1.2	1	6.4	2.2	6.1	2.8	5.6	0.7	2.4	2.2	3.8
SE		1.074	1.138	1.349	0.789	0.37	0.099	0.050	0.401	0.077	0.004	0.735	0.83	1.129
LSD (5%)		2.34	2.48	2.94	1.72	0.807	0.217	0.155	0.874	0.168	0.013	1.608	1.81	2.635

DE= days to emergence; DF = days to flowering; DM = days to maturity; PH = plant height/cm/; NS = number of stem/plant; TD = tuber diameter/cm/; TY = tuber yield/kg/; TN=tubers number per plant; BY = biological yield/kg/; HI = harvest index; STP = small tuber percentage; MTP = medium tuber percentage; BTP = big tuber percentage; CV= coefficient of variation; SE= standard error; LSD = least significant digit. **, *= signif$icant at $P \leq 0.001$ and $P \leq 0.05$%, respectively.

methodology advocated by Gomez and Gomez (1984). Phenotypic coefficient of variability (PCV) and genotypic coefficient of variability (GCV) and heritability in broad sense (h^2) were calculated by the formula given by Burton and De Vane (1953), and genetic advance that is the expected genetic gain was calculated by using the procedure given by Johnson et al. (1955). Correlation coefficient and path coefficient was worked out as method suggested by Dewey and Lu (1995). The estimated values were compared with table values of correlation coefficient to test the significance of correlation coefficient.

RESULTS AND DISCUSSION

Analysis of variance (ANOVA) was carried out for the quantitative characters as per the procedure outlined by Gomez and Gomez (1984). The result is presented in Table 2. The mean squares due to genotype were highly significant ($p<0.01$) for all the characters studied, which indicates the existence of sufficient genetic variability. There was low coefficient of variation values in all the characters indicating good precision of the experiment. In line with this study, Mondal et al. (2007) reported significant difference in days to emergence, plant height, number of stem per plant, big tuber percentage, and small tuber percentage per plant in 31 potato varieties. The estimated range, mean and standard errors of the studied 13 characters are shown in Table 2. Wide ranges were recorded for tuber number per plant, big tuber percentage, small tuber percentage, tuber diameter, days to flowering and biological yield. Similarly, plant height, days to 90% maturity, number of stems per plant, tuber yield per plant had wide ranges. The range for number of stems per plant was from 3.8 for Gera to 9.7 for Jalenie. Khayatnezhad et al. (2011) reported that the height of potato plants vary from 28.4 to 71.2 cm, whereas days to 50% emergence, days for 50% flowering, days to 90% physiological maturity, tuber diameter, and biological yield were 20.5-29, 0-70.5, 97-116, 3.75-5.26cm, 0.66-1.76 kg, respectively.

Tuber yield per plant ranged from 0.66 kg per plant for Sako to 1.76 kg for Gudanie. Maximum tuber yield per plant were observed in Gudanie (1.76 kg), Jalenie (1.49 kg), Gabissa (1.42 kg), and Bule (1.43 kg) while low yield were obtained for Sako, Tolcha, Fako, Mesno and Merachare, 0.66, 0.89. 0.95, 0.97 and 0.96 kgs, respectively. The mean tuber yield per plant was 1.17 kg per plant. The range and mean values in this study suggest the existence of sufficient variability among the tested genotypes for the majority of the characters studied and their considerable potential in the improvement of potato. The genotypic variance took relatively much of the total variances for plant height, big tuber percentage, days to flowering and small tuber percentage per plant. These effects were also detected from high heritability estimates for these characters (Table 3). On the other hand, relatively lower variances were observed for number of stem per plant, tuber yield per plant, tuber diameter and biological yield. Phenotypic coefficients of variation were found to be higher than genotypic coefficients of variation for all characters. Nevertheless, the two values differ only slightly indicating little influence of the environmental factors. This observation was in conformity with that of Sattar et al. (2007).

Tuber yield and number of stems per plant had moderate genotypic and phenotypic coefficients of variation, and hence these characters provide practically average chance for selection. On the contrary, days to maturity and tuber diameter had the least phenotypic and genotypic coefficients of

Table 3. Estimates of ranges, standard error (SE), phenotypic (∂^2_p) and genotypic (∂^2_g) variance, phenotypic (PCV) and genotypic coefficient of variability (GCV), broad sense heritability (H), expected genetic advances (GA) and genetic advance as percent of the mean (GA %) for 13 characters studied.

Character	Range	Mean ± SE	∂^2_p	$\partial^2 g$	∂_e^2	PCV	GCV	H (%)	GA	GA (%)
DE	20.5-29	24.9±1.07	17.94	7.81	1.15	17.04	11.25	44	3.79	15.25
DF	0-70.5	60.0±1.14	678.30	337.85	1.29	43.4	30.6	50	1.02	1.7
DM	97-116	108.8±1.35	86.37	41.37	1.82	8.54	5.91	48	9.15	8.4
PH	26.7-99	78.0±0.79	879.8	439.29	0.62	38.02	26.82	50	30.5	39.1
NS	3.8-9.7	5.8±0.3702	5.93	2.83	0.14	42.26	29.19	48	2.4	41.6
TD	3.57-5.26	4.5±0.0994	0.50	0.48	0.001	15.82	15.49	95.96	1.39	31.2
TY	0.66-1.76	1.2±0.0504	0.19	0.09	0.01	37.18	25.57	47	0.41	35.3
TN	10.1-24.4	14.6±0.4011	38.47	19.07	0.16	42.52	29.94	49.6	6.32	43.3
BY	0.67-1.92	1.4±0.0769	0.28	0.13	0.06	38.78	26.78	47.7	0.52	38.0
HI	0.55-0.98	0.9±0.00419	0.023	0.011	0.001	17.45	12.31	49.8	0.15	17.4
STP	4.6-57.4	30.3±0.738	477.52	238.21	0.54	72.07	50.90	49.8	22.4	73.8
MTP	27.8-49.0	37.5±0.831	79.71	39.16	0.69	23.82	16.71	49.1	9.02	24.08
BTP	0.5-65.7	32.2±1.209	753.52	375.3	1.47	85	60	49.8	28.1	87.3

DE = days to emergence; DF = days to flowering; DM = days to maturity; PH = plant height/cm/; NS = number of stem/plant; TD = tuber diameter/cm/; TY = tuber yield/kg/; TN=tubers number per plant; BY = biological yield/kg/; HI = harvest index; STP = small tuber percentage; MTP = medium tuber percentage; BTP = big tuber percentage; CV= coefficient of variation; SE= standard error; LSD = least significant digit. **, *= signif$icant at $P \leq$ 0.001 and $P \leq$ 0.05%, respectively.

variation, and hence these traits provide practically less chance for selection. Higher heritability estimates were obtained for tuber diameter (95.96%), days to 50% flowering (50%) and plant height (50%). These characters, therefore, may respond effectively to phenotypic selection. The low genetic advances for characters like days to flowering and tuber diameter, in spite of their more than 50% heritability, is due to low variability. This shows the importance of genetic variability in improvement through selection.

Genotypic correlation coefficients were found to be higher in magnitude than that of the phenotypic correlation coefficients, which clearly indicated the presence of inherent association among various characters (Table 3). Higher genotypic correlations than phenotypic ones might be due to modifying or masking effect of environment in the expression of these characters under study.

Correlation of tuber yield per plant with yield related characters

Tuber yield was positively correlated with plant height, biological yield, harvest index and big tuber percentage at both phenotypic and genotypic level (Table 4). In contrast, it was negatively correlated with small tuber percentage and medium tuber percentage at genotypic and phenotypic levels. Hence, making simultaneous increase for these characters with tuber yield per plot is difficult.

The phenotypic and genotypic associations between days to flowering and days to maturity were highly significant and positive (r_{ph} = 0.611 and r_g = 0.804) (Table 4). This will indicate that selecting for these characters will lead to early maturing genotypes.

Days to emergence was negatively correlated with tuber diameter at both the genotypic and phenotypic levels (r_g=-0.227 and r_{ph}=-0.177). Negative

Table 4. Correlation coefficients at genotypic (above diagonal) and phenotypic (below diagonal) levels of various characters.

	DE	DF	DM	PH	NS	TN	TD	TY	BY	HI	STP	MTP	BTP
DE		0.347	0.342	0.330	0.474	-0.678**	-0.227	0.115	0.114	-0.252	-0.234	0.285	0.206
DF	-0.140		0.804**	0.083	-0.345	-0.425	-0.338	-0.484	-0.503	-0.111	-0.072	0.240	-0.043
DM	0.049	0.611**		0.353	-0.435	-0.299	-0.300	-0.307	-0.327	-0.050	-0.251	0.034	0.229
PH	-0.525**	0.728**	0.313		-0.220	-0.183	-0.102	0.151	0.152	0.156	-0.009	-0.107	0.242
NS	-0.243	-0.214	-0.049	0.155		-0.031	-0.146	0.614*	0.637*	-0.218	0.033	0.301	-0.047
TN	-0.332	-0.109	-0.369	0.268	0.318		-0.083	0.415	0.446	0.072	-0.086	-0.217	0.141
TD	-0.177	0.531**	0.424*	0.401*	-0.323	-0.411*		-0.0005	-0.048	0.276	-0.134	-0.520	0.137
TY	-0.656**	0.436*	0.324	0.513**	-0.032	-0.071	0.622**		0.989**	0.238	-0.034	-0.257	0.294
BY	-0.492*	0.534**	0.444*	0.621	0.005	-0.111	0.664**	0.854**		0.121	-0.048	-0.253	0.322
HI	-0.133	-0.381	-0.321	-0.426*	-0.042	0.049	-0.253	0.036	-0.485		0.253	-0.113	-0.227
STP	0.501**	-0.503**	-0.404*	-0.533**	-0.064	0.372	-0.601**	-0.637	-0.656**	0.206		0.445	-0.863 **
MTP	-0.057	-0.274	-0.257	-0.087	0.309	0.797**	-0.602**	-0.352	-0.256	-0.102	0.518**		-0.724 **
BTP	-0.371	0.489*	0.402*	0.445*	-0.061	-0.560**	0.672**	0.616**	0.598**	-0.126	-0.959**	-0.736**	

Table 5. Phenotypic direct effect (bold face) and indirect effect (off diagonal) of various characters on tuber yield per plant.

Character	DE	DF	DM	PH	NS	TN	TD	BY	HI	MTP	BTP	r_{ph}
DE	**-0.006**	-0.005	-0.001	-0.047	0.004	0.010	-0.004	-0.531	-0.083	-0.002	0.003	-0.66
DF	0.000	**0.037**	-0.013	0.066	0.003	0.003	0.013	0.576	-0.236	-0.010	-0.003	0.44
DM	0.000	0.023	**-0.021**	0.028	0.001	0.011	0.010	0.479	-0.199	-0.0009	-0.003	0.32
PH	0.003	0.026	-0.007	**0.091**	-0.002	-0.008	0.009	0.671	-0.265	-0.003	-0.003	0.51
NS	0.001	-0.008	0.002	0.015	**-0.016**	-0.009	-0.008	0.005	-0.026	0.012	0.000	-0.03
TN	0.002	-0.004	0.008	0.024	-0.005	**-0.031**	-0.009	-0.119	0.030	0.029	0.004	-0.07
TD	0.001	0.019	-0.009	0.036	0.005	0.013	**0.024**	0.717	-0.157	-0.022	-0.005	0.62
BY	0.003	0.019	-0.009	0.057	0.000	0.003	0.016	**1.080**	-0.302	-0.009	-0.004	0.85
HI	0.001	-0.014	0.007	-0.038	0.001	-0.010	-0.006	-0.524	**0.622**	-0.004	0.001	0.04
MTP	0.000	-0.010	0.005	-0.008	-0.005	-0.024	-0.014	-0.276	-0.063	**0.037**	0.005	-0.35
BTP	0.002	0.018	-0.008	0.040	0.001	0.002	0.016	0.646	-0.078	-0.027	**-0.007**	0.62

DE= days to emergence; DF = days to flowering; DM = days to maturity; PH = plant height/cm/; NS = number of stem/plant; TD = tuber diameter/cm/; TY = tuber yield/kg/; TN=tubers number per plant; BY = biological yield/kg/; HI = harvest index; STP = small tuber percentage; MTP = medium tuber percentage; BTP = big tuber percentage.

correlation between two traits implies selection for improving one character will likely cause decrease in the other character.

Path coefficient analysis

It is evident from the result of the study that high consideration should be placed on biological yield, harvest index, tuber diameter, medium tuber percentage, days to flowering and plant height to improve potato yield at phenotypic level, since they showed positive direct effects; with special emphasis on biological yield and harvest index (Table 5). This finding is in agreement with those of Sattar et al. (2007) who showed that, plant height and biomass yield contributed direct effect to tuber yield indicating their importance as selection index for yield improvement.

The genotypic path analysis indicated that biological yield per plant and harvest index showed positive and significant correlation, therefore, these

Table 6. Genotypic direct effect (bold face) and indirect effect (off diagonal) of various characters on tuber yield.

Character	DE	DF	DM	PH	NS	TN	TD	BY	HI	MTP	BTP	r_g
DE	**0.091**	-0.004	-0.002	0.042	-0.013	0.022	-0.006	0.123	-0.159	0.017	0.004	0.12
DF	0.032	**-0.011**	-0.005	0.101	0.021	0.014	-0.008	-0.540	-0.069	0.014	-0.033	-0.48
DM	0.031	-0.009	**-0.006**	0.044	0.006	0.009	-0.008	-0.353	-0.032	0.002	0.004	-0.31
PH	0.33	-0.141	-0.122	**0.126**	0.001	0.003	-0.123	0.041	0.088	-0.056	0.004	0.15
NS	0.043	0.024	0.013	-0.022	**-0.028**	0.021	-0.004	0.687	-0.137	0.018	-0.001	0.61
TN	-0.062	0.005	0.002	-0.023	0.002	**-0.032**	-0.002	0.48	0.045	-0.013	0.003	0.41
TD	-0.003	0.002	0.001	-0.143	0.005	0.002	**0.025**	0.074	-0.041	0.002	0.075	-0.001
BY	0.001	0.003	0.005	0.009	-0.048	-0.024	-0.031	**1.079**	0.056	-0.047	-0.014	0.99
HI	-0.143	0.011	-0.24	0.004	0.001	-0.24	0.003	0.003	**0.630**	-0.322	0.53	0.24
MTP	0.026	-0.003	0.002	-0.013	-0.008	0.019	-0.013	-0.242	-0.071	**0.059**	-0.013	-0.26
BTP	0.019	0.011	-0.001	0.05	0.021	-0.005	0.017	0.347	-0.14	-0.043	**0.018**	0.29

characters are more important than other traits for the genetic improvement of potato (Table 6).

The residual effect of the genotypic path analysis (0.04) clearly indicated that about 96% of the variability in yield per plant was contributed by the 11 characters studied.

In conclusion, analysis of variance showed the presence of highly significant differences among the tested genotypes for the characters considered which indicates the existence of notable genetic variability and there was less coefficient of variation in all of the characters indicating good precision of the experiment. Tuber yield was positively correlated with plant height, biological yield, harvest index and big tuber percentage at both phenoltypic and genotypic level. In contrast, it was negatively correlated with small tuber percentage and medium tuber percentage at genotypic and phenotypic levels.

Within the scope of the path analysis carried out in the present investigation, it is, therefore, sug-gested that biological yield per plant and plantheight which are the main components of yield should be given high priority in the selection programme.

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