Associations among Yield and Yield-related Characters in Potato (*Solanum tuberosum* L.)

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Abstract

Twenty potato (*Solanum tuberosum* L.) *genotypes were tested at Ankober (3100 masl), Ethiopia, during the 2002 main rainy season to estimate the nature and magnitude of correlations and path coefficient analysis among eleven characters. The experiment was laid out in RCB design with three replications on a plot size of 6.75 m^2. Highly significant differences ($P < 0.01$) were observed among the genotypes for all the characters studied. The result of the experiment indicated that though genotypic correlations were higher in magnitude than that of phenotypic correlations, the direction of phenotypic correlation coefficients were the same as that of corresponding genotypic ones for majority of the characters. At genotypic level, tuber yield per plant was positively and significantly ($P < 0.01$) correlated with stem number per hill ($r_g = 0.588$) and leaf area per plant ($r_g = 0.759$). Path coefficient analysis at genotypic level also indicated that these characters had positive indirect effects on tuber yield via tuber number per plant. This result suggested the possibility of simultaneous selection of stem number per hill and leaf area per plant with tuber number per plant to maximize tuber yield. Path coefficient analysis at genotypic level further indicated that average tuber weight, tuber number per plant, above ground biomass and internode number are important components of tuber yield per plant. Positive and high magnitude direct effect of average tuber weight and tuber number per plant, and their relatively high negative indirect effects on tuber yield per plant via each other indicated the need to be cautious during simultaneous selection for improving tuber yield per plant.*

Key words: Characters, correlation, genotypes, path coefficient analysis, potato

Introduction

Potato (S*olanum tuberosum* L.) has considerable importance as food and cash crop in the highlands and mid altitude areas of Ethiopia and it is predominantly produced by subsistence farmers. However, the national crop productivity average is very low with only 7.2 tones/ha as compared to that of the world (16.8 tones) and the African countries (10.8 tones/ha) (FAO, 2009). Low productivity of the crop in the country has been attributed to several factors such as low yield potential and susceptibility of the local varieties to diseases, poor fertility status of the soil, lack of healthy and quality planting material and unsatisfactory water and nutrient management (Berga Lemaga *et al.*, 1994).

Among the stated constraints, lack of high yielding and disease resistant varieties are the predominant limiting factors influencing crop productivity with the crop production scenario dominated by local varieties. Most of the local varieties are susceptible to late blight (*Phytophthora infestans*) and a number of viral diseases (Gebremedhin Woldegiorgis *et al.*, 2008). To alleviate these problems, more than 25 potato varieties have been released so far for production in the country by introducing germplasm from the Netherlands, Peru and Kenya. Several of these varieties, however, are now out of production owing largely to disease susceptibility, low productivity and quality. It is therefore essential to devise a strategy of breeding potatoes for yield, quality, disease resistance and adaptability to different agro-ecologies prevailing in the country by utilizing the introduced materials as a base population.

Precise knowledge on the interrelationships of characters with each other and with yield is useful in the improvement of complex character such as yield for which direct selection has not been found much effective (Singh, 1983). Yield is a complex trait in potato and is generally considered to have low heritability (Lynch and Kozub, 1991). Hence, indirect selection *via* component characters could prove useful in bringing about genetic improvement of this character. The correlation coefficients though are useful in examining relationships between various characters; they do not provide a measure of the impact of the interrelationship among the yield components to the formation of tuber yield. Thus, path coefficients are used to partition the correla tion coefficients into direct and indirect effects in order to provide more detailed information on the nature of these relationships (Dewey and Lu, 1959).

There is still no consensus among the available results with regard to character associations in potato. The reported variations appear to be due to the type of materials used and the environmental conditions under which the genotypes were appraised (Gopal, 1999). It is based on this background that genetic association study for tuber yield and yield-related characters was undertaken using some of the potato genotypes introduced into the country in the past. Therefore, this study was undertaken to: i) determine phenotypic and genotypic correlations among tuber yield and yield related characters, and ii) assess the extent of direct and indirect effects of yield related traits on tuber yield.

Materials and Methods

Experimental location and materials

Twenty potato genotypes including four released varieties were tested at Ankober (3100 m.a.s.l) during the main rainy season of 2002. The details of the genotypes are presented in Table 1. The testing area received an annual rainfall of 1728 mm (average of three consecutive years data) distributed bimodally over *belg* and main rainy seasons. The soil type of the site is Cambisol, with a pH of

5.83, organic carbon content of 2.97 per cent, total N (0.3 per cent), available P (80.36 ppm) and K (0.92 meq/100 g).

Experimental design and management

The experiment was laid out in a randomized complete block design with three replications. Well-sprouted tubers of each genotype were planted in three rows of 10 hills on a plot size of 6.75 m^2 (2.25m x 3 m) with a spacing of 75 cm between rows and 30 cm between hills. A fertilizer rate of 110 kg/ha N and 90 kg/ha P_2O_5 in the form of Urea and DAP, respectively, was applied as per the recommendation of Holetta Agricultural Research Center (Gebremedhin *et al.*, 2008). Phosphorus was applied at planting whereas nitrogen was applied in two splits, the first–half during planting and the remaining 45 days after planting. Cultivation was carried out twice in the growing season. Ridomil MZ 65% was sprayed twice during crop growth to protect the crop from late blight (*Phytophthora infestance*) damage.

Table 1. Description and source of potato genotypes tested at Ankober in 2002

Genotype	Source	Country	Remarks
CIP-382146.27	CIP[1]	Peru	-
CIP-381169.16	CIP	Peru	-
CIP-384321.9	CIP	Peru	-
CIP-389701.3	CIP	Peru	-
CIP-387675.20	CIP	Peru	-
CIP-385021.18	CIP	Peru	-
CIP-387412.2	CIP	Peru	-
CIP-386031.4	CIP	Peru	-
CIP-387744.1	CIP	Peru	-
CIP-385021.26	CIP	Peru	-
KP-90108.5	CIP	Kenya	-
KP-90188.3	CIP	Kenya	-
KP-90134.2	CIP	Kenya	-
KP-90138.12	CIP	Kenya	-
KP-90134.5	CIP	Kenya	-
KP-90147.73	CIP	Kenya	-
Tolcha	Holetta ARC[2]	Ethiopia	Released for areas between 1800-3000 masl
Gorebella	Debre Birhan ARC	Ethiopia	Released for areas between 2700-3200 masl
Menagesha	Holetta ARC	Ethiopia	Released for areas above 2400 masl
Zengena	Adet ARC	Ethiopia	Released for areas between 2000-2800 masl

[1]CIP: International Potato Center; [2]ARC: Agricultural Research Center

Data collection and statistical analysis

Ten plants were randomly selected in each plot to collect data on ten characters. However, leaf area per plant was measured on five plants per plot. Plant height (PH) was recorded in cm from the ground level to the tip of mature plant. Internode number (ITN) counted on the longest stem of mature plant. Number of stems per hill (NSH) recorded by counting the number of primary stems per hill. All of these characters were recorded at the stage when 75% of the plants per plot produced the first flower. Leaf area per plant (LAP) estimated using a portable leaf area meter and expressed as cm^2. Above ground biomass (AGB) representing haulm dry weight, was recorded at harvest and expressed in grams.

Days to flowering (DTF) noted as the actual number of days from emergence to a stage when 50% of the plants in the plot produced the first flower, days to maturity (DTM) counted as the number of days required from emergence to a stage when haulms of 50% of plants in a plot manifested yellowing, tuber number per plant (TNPP) recorded as the number of tubers collected from a plant at harvest, tuber weight (TW) recorded as average weight of a tuber in gram at harvest, tuber yield (TY) measured as total weight of tubers in g per plant at harvest, and tuber dry matter content (TDM) measured from a composite tuber sample of five tubers harvested within 24 hours. A 100 gram tuber was chopped and dried at 70 ^{o}C for about 48 hours in forced hot air circulated oven, and the values were expressed in percentage.

Mean data of plants per plot were used for further statistical analysis. Tuber yield was considered as a resultant variable while ten other characters were considered as the causal variables. Phenotypic and genotypic correlations were computed by calculating variances and then covariances at phenotypic and genotypic levels, by using the formula suggested by Miller *et al.* (1958). The direct and indirect effects of the independent characters on tuber yield were estimated by the formula of Dewey and Lu (1959).

Results and Discussion

Analysis of variance

The data showed that the mean squares due to genotypes were highly significant (P< 0.01) for all the eleven characters evaluated. This implied the existence of diversity among the genotypes, which allowed carrying out correlation and path analyses (Naik *et al.*, 1998).

The mean values of the characters for the 20 genotypes are presented in Table 2. About 45% of the tested genotypes gave tuber yields greater than a kilogram per plant. Among the genotypes studied, Gorebella (1.4 kg), Kp-90138.12 (1.3 kg), Kp-90147.73 (1.3 kg), Kp-90134.5 (1.3 kg) and CIP-387744.1 (1.3 kg) gave significantly (P< 0.01) higher tuber yield per plant. All of the tested genotypes gave tubers with a dry matter content of above 23%. In general, dry matter content of more than 20% is considered acceptable for food processing (CIP, 2007). This indicated that Ankober and similar cool highland areas are suitable for production of potatoes for processing.

Estimation of phenotypic and genotypic correlations

The estimates of phenotypic and genotypic correlation coefficients among the characters studied are presented in Table 3. In most cases, the direction of phenotypic correlation coefficients was similar to that of the corresponding genotypic correlation coefficients. The magnitude of genotypic correlations were higher than the corresponding phenotypic ones for most characters suggesting inherent associations among various characters independent of the environmental influence.

Table 2. The mean values of eleven characters of 20 potato genotypes at Ankober in 2002

Variety	PH	ITN	NSH	DTF	DTM	AGB	TNPP	TW (g)	TDM	LAP	TY (g)
CIP-382146.27	52.8	13.67	3.0	43	107	53.93	13	89.40	27.78	7834.6	975.32
CIP-381169.16	42.2	11.67	3.7	46	101	61.22	25	50.17	27.10	9028.3	1182.84
CIP-384321.9	48.2	12.33	3.7	51	104	54.95	24	30.56	31.79	9043.3	690.20
CIP-389701.3	42.1	11.33	3.3	36	98	59.44	31	35.35	23.43	7170.3	1074.05
CIP-387675.20	57.3	13.67	4.3	51	98	66.15	15	64.73	27.16	5979.4	906.96
CIP-385021.18	38.8	12.67	3.0	48	119	64.46	15	63.82	31.49	6918.8	853.67
CIP-387412.2	37.3	11.33	2.3	43	114	53.04	11	65.27	29.29	4455.4	675.45
CIP-386031.4	43.9	11.33	4.0	32	106	46.94	14	82.44	26.68	7276.8	979.20
CIP-387744.1	71.6	15.00	5.0	47	117	77.79	23	56.69	29.30	9403.6	1253.02
CIP-38521.26	36.5	10.33	5.7	43	99	46.34	13	79.29	26.78	7673.5	989.90
KP-90108.5	58.9	14.67	5.0	44	98	65.47	18	61.84	24.17	5398.7	1087.36
KP-90188.3	34.6	11.33	3.3	40	98	46.79	14	48.86	27.33	5916.9	654.29
KP-90134.2	59.2	14.67	5.7	44	98	57.35	17	61.38	25.04	7323.2	1034.42
KP-90138.12	47.1	12.33	4.0	34	100	65.95	14	97.17	27.73	8134.4	1287.40
KP-90134.5	61.1	14.67	5.0	48	105	71.19	12	117.56	26.18	8038.3	1260.24
KP-90147.73	59.7	13.33	8.3	46	110	74.48	38	34.20	28.26	9870.8	1264.60
Tolcha	43.0	10.67	3.0	42	100	50.61	14	73.26	28.24	6492.0	874.63
Gorebella	57.1	12.33	5.7	36	111	73.05	15	93.84	29.28	8866.1	1401.58
Menagesha	55.0	11.67	4.7	37	117	87.41	12	70.21	24.03	5654.0	798.60
Zengena	74.2	15.67	4.3	52	105	72.11	21	42.01	27.30	5658.7	798.64
Mean	51.03	12.73	4.35	43.15	105.25	62.43	17.95	65.90	27.42	7306.85	1002.12
LSD (5%)	4.706	1.157	1.096	4.394	4.994	11.473	3.764	14.435	1.554	1798.68	177.796
CV (%)	5.575	5.499	15.239	6.169	2.868	11.109	12.734	13.242	3.428	14.881	10.725

PH = plant height (cm), ITN = internode number, NSH = number of stems per hill, DTF = days to flowering, DTM = days to maturity, AGB = above ground biomass, TNPP = tuber number per plant, TW = average tuber weight (g), TDM = tuber dry matter content in %, LAP = leaf area per plant in cm^2, TY = tuber yield per plant

At phenotypic and genotypic levels, tuber yield per plant was positively and significantly correlated with stem number per hill (r_p= 0.536 and r_g= 0.588) and leaf area per plant (r_p= 0.529 and r_g= 0.759). This is supported by the observation of the present study that high yielding genotypes, Gorebella, KP-90147.73, KP- 90134.5 and KP-90134.2 had the highest stem number per hill (Table 2). De la Morena *et al.* (1994) also indicated that variation in tuber yield among cultivars was associated with the density of stems.

In support of this observation, Baye Berihun *et al*. (2005) reported high positive correlation between tuber yield per plant and leaf area per plant at genotypic level. Such a relationship explained the intimate relationship between leaf area and dry matter partitioning (Beukema and Vanderzaag, 1979) which is governed by the genotype.

Though they exhibited moderate and positive correlation with tuber yield, a strong negative correlations (r_p = -0.697 and r_g = -0.713) were observed between tuber number per plant and average tuber weight both at phenotypic and genotypic levels. Genotypic correlation between tuber number per plant and leaf area per plant (r_g = 0.602) was strong and positive suggesting that genotypes with high leaf area could produce high number of tubers (Table 2). At phenotypic and genotypic levels, correlation between tuber number per plant and number of stems per hill was significant and positive (r_p = 0.452 and r_g = 0.453). This is attributable to higher leaf area per plant as obtained under high stem densities resulting in higher dry matter production and partitioning (Rasul *et al.*, 1995).

Relatively high magnitude genotypic correlation (r_g = 0.478) was observed between days to maturity and dry matter content. This implied that late maturing genotypes had higher tuber dry matter content (Table 2) possibly arising from higher bulking duration (Beukema and Vanderzaag, 1979). This suggested that any improvement in days to maturity could also lead to improvement in tuber dry matter production. The genotypic correlation between days to maturity and above ground biomass was strong, suggesting that most genotypes producing high above ground biomass turned out to be late maturing. High magnitude positive correlation of days to flowering with internode number at both phenotypic and genotypic levels indicated that genotypes with higher number of nodes were late in flowering. Significant and positive genotypic correlations were obtained among the majority of plant characters (Table 3). The genotypic correlation between number of stems per hill and leaf area per plant was strong (r_g = 0.541). Allen and Scott (1980) further endorsing the above view highlighted the importance of rapid development of a high leaf area index by increasing the number of stems per unit area in order to improve assimilation processes during early growth stages. In the present study, the observed correlations indicated that it may be possible to exploit characters like number of stems per hill and leaf area per plant in efforts to improve tuber yield per plant in view of the high magnitude positive correlations between these pairs of characters at genotypic level. Such an approach could lead to correlated responses to selection that with increase in one character may lead to the increment of the other.

Table 3. Estimates of phenotypic (above diagonal) and genotypic (below diagonal) correlation coefficients among eleven characters using 20 potato genotypes at Ankober, Ethiopia in 2002.

	PH	ITN	NSH	LAP	DTF	DTM	AGB	TNPP	TW	TDM	TY
PH		0.837**	0.472*	0.179	0.396	0.176	0.661**	0.202	-0.006	-0.121	0.356
ITN	0.895++		0.275	0.063	0.509*	0.082	0.491*	0.113	0.004	-0.054	0.266
NSH	0.531+	0.373		0.388	0.112	0.025	0.373	0.452*	-0.061	-0.151	0.536*
LAP	0.196	0.098	0.541++		0.069	0.102	0.1	0.439	0.013	0.234	0.529*
DTF	0.425	0.611++	0.103	0.043		0.09	0.173	0.206	-0.34	0.333	-0.17
DTM	0.193	0.106	0.025	0.091	0.037		0.412	-0.057	0.054	0.387	-0.02
AGB	0.729++	0.523+	0.5+	0.216	0.166	0.579++		0.224	0.024	-0.091	0.412
TNPP	0.211	0.154	0.453+	0.602++	0.199	-0.057	0.212		-0.697**	-0.011	0.335
TW	-0.001	-0.016	-0.024	-0.006	-0.343	0.071	0.019	-0.713++		-0.073	0.354
TDM	-0.12	-0.057	-0.195	0.395	0.379	0.478+	-0.129	-0.02	-0.083		-0.13
TY	0.386	0.269	0.588++	0.759++	-0.214	0.011	0.404	0.302	0.395	-0.161	

** = Significant at 1 % probability level; * = significant at 5 % probability level for the phenotypic correlation coefficients
++ = Significant at 1 % probability level; + = significant at 5 % probability level for genotypic correlation coefficients

PH = plant height, ITN = internode number, NSH = number of stems per hill, DTF = days to flowering, DTM = days to maturity, AGB = above ground biomass, TNPP = tuber number per plant, TW = average tuber weight, TDM = tuber dry matter content, LAP = leaf area per plant, TY = tuber yield per plant

Path coefficient analysis

In this study, each of the characters considered did influence tuber yield per plant either directly or indirectly. The phenotypic and genotypic direct and indirect effects of characters on tuber yield per plant are presented in Tables 4 and 5. It is interesting to note here that most of the characters that exerted low direct effects at phenotypic level manifested relatively higher magnitude genotypic direct effects. This highlighted the presence of inherent associations among different characters with tuber yield per plant, independent of the environmental influence. Similar observation has been reported by Baye Berihun *et al.* (2005).

At genotypic level, average tuber weight exerted relatively higher positive direct effect on tuber yield per plant (0.767) followed by tuber number per plant (0.652), above ground biomass (0.555) and internode number (0.531). This indicated that these characters are important contributors to tuber yield per plant. This result is in agreement with the reports of Naik *et al*. (1998) and Birhman and Kang (1993), who considered average tuber weight as more important component of tuber yield per plant than tuber number per plant. Their view corroborated the observations of the present study that average tuber weight is of greater consequence to tuber yield per plant (Table 5). However, relatively higher magnitude negative indirect effects of this character on tuber yield were observed *via* tuber number per plant. Sizable magnitude of positive correlations of average tuber weight and tuber number per plant with tuber yield per plant and their relatively high negative indirect effects on tuber yield *via* each other suggested the relevance of simultaneous selection of these characters with appropriate weight score to improve tuber yield per plant.

Leaf area per plant and number of stems per hill though exhibited high magnitude positive correlation with tuber yield per plant; their direct effects on tuber yield were low. Such a relationship emerged as a result of its relatively higher indirect effect *via* tuber number per plant. Lynch and Kozub (1991) reported similar results for most of their genotypes with regard to indirect contribution of number of stems on tuber yield *via* tuber number per plant. This suggested that for improving tuber yield per plant, simultaneous selection of tuber number per plant and these characters is essential. Unlike that of phenotypic path coefficients, days to maturity (-0.435), days to flowering (-0.423) and plant height (-0.396) exerted relatively higher negative genotypic direct effects on tuber yield per plant. Similarly, Werner *et al.* (1998) indicated that days to maturity and plant height exhibited negative direct effects on tuber yield per plant. However, days to maturity showed positive indirect effects on tuber yield *via* above ground biomass (0.321) and tuber dry matter content (0.123). A residual effect of 0.243 computed at genotypic level indicated that the ten potato characters considered in this study could account for 75.7% of the variability in tuber yield per plant. This pointed out to the fact that these characters could determine high proportion of the variability for tuber yield per plant.

Table 4. Estimate of direct (bold diagonal) and indirect effects of characters at phenotypic level on tuber yield per plant using 20 potato genotypes at Ankober, Ethiopia , in 2002

	PH	ITN	NSH	LAP	DTF	DTM	AGB	TNPP	TW	TDM	r_p
PH	**-0.071**	0.169	0.054	0.016	-0.069	-0.02	0.118	0.173	-0.005	-0.008	0.356
ITN	-0.059	**0.202**	0.032	0.005	-0.088	-0.009	0.087	0.097	0.003	-0.004	0.267
NSH	-0.033	0.056	**0.115**	0.034	-0.02	-0.003	0.066	0.386	-0.055	-0.010	0.537
LAP	-0.013	0.013	0.045	**0.088**	-0.012	-0.012	0.018	0.376	0.011	0.016	0.530
DTF	-0.028	0.103	0.013	0.006	**-0.174**	-0.01	0.031	0.176	-0.307	0.022	-0.170
DTM	-0.012	0.017	0.003	0.009	-0.016	**-0.114**	0.073	-0.049	0.049	0.026	-0.010
AGB	-0.047	0.099	0.043	0.009	-0.03	-0.047	**0.178**	0.191	0.021	-0.006	0.412
TNPP	-0.014	0.023	0.052	0.039	-0.036	0.007	0.040	**0.855**	-0.629	-0.001	0.336
TW	0.000	0.001	-0.007	0.001	0.059	-0.006	0.004	-0.596	**0.902**	-0.005	0.353
TDM	0.009	-0.010	-0.017	0.021	-0.058	-0.044	-0.016	-0.010	-0.065	**0.067**	-0.130
										R	0.402

R = residual effect
r_p = phenotypic correlations of characters with tuber yield per plant
PH = plant height in cm, ITN = internode number, NSH = number of stems per hill, DTF = days to flowering, DTM = days to maturity, AGB = above ground biomass, TNPP = tuber number per plant, TW = average tuber weight in gram, TDM = tuber dry matter content and *LAP = leaf area per plant,*

Table 5. Estimates of direct (bold diagonal) and indirect effects of characters at genotypic level on tuber yield per plant using 20 potato genotypes at Ankober, Ethiopia

	PH	ITN	NSH	LAP	DTF	DTM	AGB	TNPP	TW	TDM	r_g
PH	**-0.396**	0.475	0.017	0.042	-0.179	-0.084	0.404	0.138	-0.001	-0.031	0.385
ITN	-0.354	**0.531**	0.012	0.021	-0.258	-0.046	0.29	0.100	-0.013	-0.015	0.268
NSH	-0.210	0.198	**0.032**	0.117	-0.043	-0.011	0.277	0.296	-0.018	-0.050	0.588
LAP	-0.077	0.052	0.017	**0.216**	-0.018	-0.039	0.120	0.393	-0.005	0.102	0.760
DTF	-0.168	0.324	0.003	0.009	**-0.423**	-0.016	0.092	0.130	-0.263	0.097	-0.210
DTM	-0.076	0.056	0.001	0.02	-0.015	**-0.435**	0.321	-0.037	0.055	0.123	0.012
AGB	-0.288	0.277	0.016	0.047	-0.070	-0.252	**0.555**	0.138	0.015	-0.033	0.405
TNPP	-0.083	0.082	0.014	0.130	-0.084	0.025	0.118	**0.652**	-0.547	-0.005	0.301
TW	0.000	-0.010	-0.001	-0.001	0.145	-0.031	0.011	-0.465	**0.767**	-0.021	0.395
TDM	0.048	-0.030	-0.006	0.085	-0.160	-0.208	-0.072	-0.013	-0.063	**0.257**	-0.160
										R	0.243

R = residual effects
r_g = genotypic correlation of characters with tuber yield per plant
PH = plant height, ITN = internode number, NSH = number of stems per hill, DTF = days to flowering, DTM = days to maturity, AGB = above ground biomass, TNPP = tuber number per plant, TW = average tuber weight, TDM = tuber dry matter content, LAP = leaf area per plant

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