ETHIOPIAN JOURNAL OF AGRICULTURAL SCIENCES

June 2005

ISSN O257-2605
Vol. 18 No. 1

ETHIOPIAN JOURNAL OF AGRICULTURAL SCIENCES

Editorial Board

Ethiop. J. Agric. Sci. 18: 103-121 (2005)

Variability and Association of Tuber Yield and Related Traits in Potato (*Solanum tuberosum* L.)

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Abstract

Thirty genotypes of potato were evaluated to estimate the nature and magnitude of variability and associations among tuber yield and related characteristics. Significant genotypic variability among the test genotypes were observed for plant height, stem number per plant, haulm dry weight, tuber number per plant, and average tuber weight. High heritability coupled with high genetic advance as a per cent of mean were recorded for haulm dry weight, plant height, average tuber weight, tuber protein content and stem number per plant. At genotypic level, average tuber weight and leaf area exerted high magnitude positive direct effects and also exhibited positive association with tuber yield per plant, suggesting their possible utilization to improve tuber yield per plant. Selection to improve tuber yield per plant could be feasible via leaf area and average tuber weight.

Introduction

The potato (*Solanum tuberosum* L.) is one of the important food crops of the world. It was introduced in to Ethiopia in 1858 by the German Botanist Schimper (Pankhurst 1964). In spite of the favorable production conditions in Ethiopia, the productivity is only about 7.96 tones/ha, which is extremely low in comparison to world's average productivity of about 15.19 tones/ha (FAO 1995). A number of production related problems accounting for such low productivity under Ethiopian farming conditions have been identified. The low potato productivity, among other factors is also attributed to the susceptibility of the indigenous varieties to major diseases. The main hurdle to the crop improvement appeared to be because the local varieties are of the same parentage introduced by Schimper in the late 19th

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century (HaileMichael, 1979). This clearly indicate narrow genetic base of the local varieties. The attention given to breed potatoes for high yield, protein, starch and tolerance/resistance to major biotic factors is low. Generation of data base on the extent and pattern of variability, particularly present in the existing population is essential for further improvement of the crop. Similarly, information on the extent and nature of interrelationships among different characters contributing to tuber yield is also required in formulating efficient scheme of multiple traits selection as it could offer a means of direct and indirect selection of complex characters including yield. At present, there is lack of detailed information pertaining to these aspects in respect of the population available in the country. This is a pre-requisite for designing effective crop improvement strategies specially focused towards high yield and stability of performance. The present study was undertaken on thirty diverse potato genotypes to determine the nature and magnitude of variability for tuber yield and related traits, and estimate associations between traits.

Materials and Methods

Experimental Site

The experiment was conducted at Rare the Department of Plant Sciences (Horticulture section) research field at Alemaya University during 2001 main cropping season. The Alemaya University campus is located at 42 ^{0} 3 ' E longitude 9^{0} 26$^{'}$ N latitude and an altitude of 1980 m.a.s.1. It is situated in the semi-arid tropical belt of eastern Ethiopia that is well known for potato cultivation by the subsistence farmers. The soil of the experimental site was a well drained deep alluvial with sub-soil stratified with loam and sandy loam that contained 3.05 per cent organic matter and 0.14 per cent nitrogen with a pH of 7.7 (Tamirie, 1973). The mean annual rainfall is about 780 mm while the mean annual maximum and minimum temperatures are 23.40 and 8.25^{0} C, respectively (Temam, 1992).

The study was carried out using 30 potato genotypes including two standard checks and advanced crosses of *S. tuberosum* with *S. phureja* and *S. andigenum* (Table 1). The experiment was laid out in a randomized complete block design (RCBD) with three replications. Each plot consisted of four rows 3m long with a row spacing of 0.75m. Tubers were planted at a spacing of 30 cm between plants accommodating 40 tubers per plot. A distance of 1m between the plots and 3m between replications was maintained. The potato tubers of the respective genotypes were planted on July 18, 2001 with spot application of phosphorus in the form of DAP at 300 kg/ha (6.75 g/hill) at the time of planting while nitrogen top-dressing (as urea) at 200 kg/ha (4.5 g/hill) was carried out after full emergence as per the recommendations of Tereissa (1995).

Statistical Procedures

Mean values of the replicated parameters were subjected to statistical analysis to compute various estimations as given below. MSTATC and Agrobase statistical package were adopted wherever applicable for the analysis of the data.

It was subjected to the analysis of variance for randomized complete block design (RCBD) following the procedure out lined by Gomez and Gomez (1984) and least significant difference (LSD) was used to separate the means. The variability present in the population was estimated by simple measures viz, range, phenotypic and genotypic variances and coefficient of phenotypic and genotypic variability following the methods described by Burton and Devane (1953).

Heritability in the broad sense on a genotypic mean basis for each characters was computed as per for the formula used by Allard (1960). The genetic advance expected under selection, assuming selection intensity of five percent was calculated by the formula suggested by Johanson *et al.,* (1955).

Phenotypic correlation is the observable correlation between two variables which includes both genotypic and environmental effects, while the genotypic correlation is the inherent association between two variables. These were computed by calculating, variances and then covariance at phenotypic and genotypic levels, by using the formula suggested by Miller *et al.* (1958).

In path coefficient analysis, tuber yield per plant was taken as the resultant (dependent) variable while the rest of the characters were considered as the causal (independent) ones. The direct and indirect effects of the independent characters on tuber yield per plant were estimated by the formula of Dewey and Lu (1959)

Data Collection

The data were recorded on plant basis on five randomly selected plants. The average of five plants was used for statistical analysis. Plant height (PH) – Plant height was measured as the distance in cm from the soil surface to the tip of the matured plant of the central row. Stem number per plant (SNPP) –The actual number of stems per hill at physiological maturity was recorded Leaf let index (LLI) -This was recorded as the ratio of diameter to length of leaf after 50 per cent flowering. Leaf area (LA) -It was estimated using a portable leaf area meter (Model CI-202-Area Meter CID. Inc., USA) and expressed as cm^2 after 50 per cent flowering.

Leaf area index (LAI) –The ratio of leaf surface to the ground area occupied, by the plant at on set of flowering was expressed as per the procedure of Firman and Allen (1989). Days to flowering (DTF) –This was recorded as the actual number of the days from emergence to 50 per cent of flowering. Days to maturity (DTM)- According to

IBPGR177 UPOV descriptor list days to maturity is recorded when 50% of the plants of an accession are ready for harvest as indicated by the senescence of haulm. Haulm dry weight (HDW) – This was recorded as dry weight of haulms (g) at physiological maturity. Tuber Number per plant (TNPP) –This was recorded as the actual number of tubers collected from a matured plant at harvest. Tuber yield per plant (TYPP) - This was recorded as the weight (g) of tubers harvested from a physiologically matured plant. Average tuber weight (ATW) -This was recorded as the ratio of the weight of tubers per plant to number of tubers per plant expressed in grams at harvest. Tuber specific gravity (TSG) – This was determined as the weight of tuber relative to that of volume of the water measured by a potato hydro meter (Model.3.6Potato Hydro meter, USA).

Tuber dry matter (TDM) –This was determined by chopping a 100gm of harvested clean tubers, dried to constant weight in forced hot air circulation oven at 70 ^{0}C for about 48 h and ratio of dry tuber weight to that of fresh weight expressed in percentage. Tuber protein content (TPC) –bulk of two gram samples from each plot were oven dried and ground to pass through 2mm size sieve mesh for determination of the total nitrogen content using the conventional micro Kjeldahl procedure. The total nitrogen content of each sample was then multiplied by standard conversion factor of 6.25 to obtain crude protein content and values were expressed in per cent (AOAC, 1970).

Results and Discussion

Analysis of variance

There were big differences between the genotypes for days to maturity (Table 1). Although it is known that maturity is influenced by growing conditions and environment (Beukema and Vanderzaag, 1979), it was observed that only 3.33 per cent of the entries turned out to be early (68.7 days) while 50 per cent, were medium (71-80 days) and 46.67 per cent were of late (81-92.7 days) maturity types.

Among the genotypes studied, CIP- 377838-1, was found to be the earliest (68.7 days) while AL-450-5 was the late (92.7 days) maturing. It may be interesting to note here that AL- 450-5, the late maturing genotype, also had significantly higher tuber dry matter content (29.47 per cent) over CIP- 377838-1, which substantiated the view that the tuber dry matter content increase with increase in the growing season (Appleman and Miller, 1926; Birhuman, 1993). Based on tuber dry matter content 3.33, 60 and 36.67 percent of the tested genotypes were grouped in to high, medium, and low respectively. This is significant from the point of view of dehydration of potato tuber and agrees with the findings of Rasui *et al.* (1995).

Furthermore this aspect appears to be attractive since, in potato tuber dry matter has been positively correlated with tuber weight and tuber yield (Birhuman, 1993).

With respect to tuber yield per plant, CIP- 381403-5 produced the highest tuber yield (1008.9g/plant) while AL-207 gave the lowest tuber yield of 536.9g/plant. Genotypes did also show differences in tuber protein content CIP-378570.4B exceeds all with 12.20% and Al-100 had the lowest (5.4%).The fact that the genotype CIP-378570-4B having maximum tuber protein content recorded significantly low tuber dry matter appears to be the justification for the negative correlation between these two parameters (Kaminski, 1977). The study thus highlighted the possibilities of exploiting the variability available pertaining to maturity, tuber dry matter and tuber yield and tuber protein content in the genotypes tested for genetic improvement of the crop.

Estimates of Phenotypic and Genotypic Variability

The phenotypic coefficient of variability (PCV) ranges from 2.89 for tuber specific gravity to 38.75 per cent in case of haulm dry weight. The genotypic coefficient of variability (GCV) ranged from almost negligible in respect of tuber specific gravity to 36.42 per cent for haulm dry weight. Maximum genetic variation was observed for haulm dry weight followed by average tuber weight, tuber number per plant, stem number, plant height, which may be attributed to the genetic diversity of the genotypes, suggesting existence of high genetic variability among the genotypes for effective selection. This view is corroborated by the observations of Sandhu and Kang (1998) in respect of plant height and stem number but it was at variance with respect to tuber yield per plant which was found to be moderate in the present study.

Tuber specific gravity showed PCV of 2.89 and almost nil GCV values indicating possibility of hardly any scope for improvement of this character through selection. Genetic variability for leaf area, leaf area index, stem number per plant, tuber dry matter and tuber protein content are relatively lower (Table 2) suggesting search for more diverse genotypes in order to ensure effective selection.

Table 1: Analysis of variance in randomised complete block design in respect of fourteen characters in some potato genotypes during 2001.

Source of variation	df	PH	SNPP	LLI	LA	LAI	DTF	DTM	HDW	TNPP	TYPP	ATW	TSG	TDM	TPC
Replication	2	187.84	3.83	0.191	0.35	5.37	2.43	300.04	112.01	23.32	65070.7	227.47	0.007	7.27	8.09
Genotypes	29	378.02**	3.75**	0.035	0.14**	3.36**	76.42**	91.46**	112.01**	18.60**	26751.2	1158.43**	0.001	9.06**	9.74**
Error	58	22.25	0.94	0.025	0.07	1.30	24.92	41.36	24.18	3.9	16033.6	139.77	0.001	2.31	2.01
C.V(%)		8.1	2.5	10.8	26.04	25.4	14.22	8.05	13.22	18.28	18.53	17.44	2.20	6.08	14.44
L.S.D(0.05)		10.45	2.14	0.35	0.54	2.41	10.99	14.2	10.72	6.97	277.1	25.99	0.1	3.32	3.22

***- indicates significant differences at 1% per cent probability level.*

PH=Plant Height, SNPP = Stem Number Per Plant, LA= Leaf Area, LAI=Leaf Area Index, DTF= Days to Flowering, DTM= Days to Maturity HDW = Haulm Dry Weight, TNPP=Tuber Number Per Plant, TYPP= Tuber Yield Per Plant,ATW=AverageTuberWeight,TSG=TuberSpecificGravity,TDM=TuberDryMatter,TPC=TuberProteinConten

Phenotypic coefficient of variability (PCV) was generally higher than genotypic coefficient of variability (GCV) for all the characters considered (Table 2). The PCV and GCV values for plant height, days to maturity, haulm dry weight, tuber dry matter, and tuber protein content differed only slightly indicating lesser influence of environmental factors. The relatively wide differences between PCV and GCV values for the other characters suggested the influence of environment in determining them. Therefore, it would be appropriate to consider the above characters depending upon the objectives of potato improvement program.

Maximum heritability percentage was obtained for haulm dry weight (88.36) followed by plant height (84.20), average tuber weight (70.84), tuber protein content (56.21), tuber number per plant (49.47) tuber dry matter (49.34).days to flowering (40.02) and leaf area index (34.67). On the same analogy, the characters, leaf area (26.32), days to maturity (28.76), tuber yield per plant (18.22) and tuber specific gravity (almost nil) had low heritability estimates.

The high h^2 obtained in this study for tuber weight, plant height and tuber number per plant agrees with earlier findings of Naik *et al,* (1998) and Sharma (1999), respectively. The low heritability estimate of days to maturity (Table 2) obtained in the present study, however, is in contrast to that of Sharma (1999) who observed high heritability values. This might probably be due to the influence of environment and growing season (Beukema and Vanderzaag, 1979).

In view of this observation, it may be reasonable to deduce that characters haulm dry weight and plant height are amenable to selection due to their high heritability estimates while it would be impractical for days to flowering, leaf area, leaf area index, days to maturity, tuber yield per plant and tuber specific gravity owing to their low heritability estimates.

The expected genetic advance as a percent of mean selecting the top 5 per cent of the genotypes (high value of the trait) varied from almost nil for tuber specific gravity to 70.45 percent for haulm dry weight (Table 2). This indicated that selecting the top 5 per cent of the base population could result in an advance of negligible value to 70.45 per cent over the population mean.

In the present study, haulm dry weight, plant height, average tuber weight tuber protein content, tuber number per plant and stem number per plant had high heritability estimates coupled with high genetic advance (Table 2). The selection for these characters is most likely to be more effective. This is in agreement with the findings of Sharma (1999) in plant height and tuber number per plant. In light of this, it may be reasonable to conclude that the characters with high heritability and genetic advance as mentioned above are amenable for selection towards improving their own potential value.

Table.2. Range, mean +SE, coefficient of variation, phenotypic (σ^2_p) , genotypic (σ^2_g) environmental, σ_e along with heritability (h^2), genetic advance (GA) and genetic advance as a per cent of mean (GAM) for various characters.

Characters	Range	G.mean +SE	Mean of check (Chero)**	σ_p^2	σ_g^2	σ_e^2	$PCV\%$	GCV%	h^2 %	GA	GAM
Plant Height	25.2-81.27	58.2+3.85	63.23	140.84	118.59	22.25	20.39	18.71	84.20	20.59	35.38
Stem Number	2.87-6.8	4.8+0.8	2.87	1.90	0.94	0.94	28.72	20.2	49.47	1.41	29.38
Leaf Area	0.478-1.53	1+0.2	1.40	0.095	0.025	0.07	30.82	15.81	26.32	0.17	17.00
Leaf Area Index	2.137.1	4.5+0.9	6.22	1.99	0.69	1.30	31.35	18.46	34..67	1.00	22.22
Days to Flowering	29.67-41	35.1+4.08	35.3	42.09	17.17	24.92	18.48	11.81	40. 02	5.35	15.24
Days to Maturity	68.67-92.67	79.9+5.53	73.3	58.06	16.70	41.36	9.54	5.12	28.76	4.52	5.66
Haulm Dry Weight	16.13-88.48	37.2+4.00	34.93	207.74	183.56	24.18	38.75	36.42	88.36	26.21	70.45
Tuber Number Per Plant	5.69-17.2	10.8+2.6	11.27	8.8	4.90	3.9	27.47	20.50	55. 86	3.42	31.67
Tuber Yield Per Plant	536.9- 1008.9	683.5+103.4	783.6	19606.14	3572.53	16033.61	20.49	8.75	18.22	52.55	7.69
Tuber Weight	73.903-122.17	67.8+9.7	68.8	479.32	339.55	139.77	32..28	27.18	70.84	31.94	47.11
Tube Specific Gravity	1.06-1.13	1.1+0.03	1.097	0.001	0.00	0.001	2.89	0.00	0.00	0.00	0.00
Tuber Dry Matter	21.2-29.5	25.0+1.2	23.73	4.56	2.25	2.31	8.54	5.99	49.34	2.16	8.64
Tuber Protein Content	5.4-12.2	9.8+1.2	11.47	4.59	2.58	2.01	21.86	1639	56.21	2.48	25.31

*** indicate Values of standard check represented that of the genotype Chero which was better than the two standard checks Adopted in the study in respect of general performance.*

Association of Characters

The estimates genotypic correlation coefficients between each pair of the characters studied are presented in Table 3. In most of the characters phenotypic correlation coefficients were lower in magnitude than the corresponding genotypic ones. This suggests an inherent association among various characters independent of the environmental influence. At phenotypic level tuber yield per plant had significant positive correlation with haulm dry weight (r = 0.443) while its association with average tuber weight was highly significant and positive (r = 0.532).This character had also, considerably high positive genotypic correlation with leaf area (r = 1.539), leaf area index (r = 1.378), haulm dry weight (r = 0.954) and average tuber weight (r = 0.708). This is corroborated by the findings of Birhuman (1993) and Maris (1969) in respect of positive correlation between tuber yield and tuber weight. The high magnitude positive association of tuber yield with leaf area, leaf area index, haulm dry weight and average tuber weight at genotypic level highlighted the efficiency of above ground parts in assimilate production and dry matter partitioning (Beukema and Vanderzaag, 1979 and Rasui *et al.* 1995).

In the present study, high value of negative genotypic correlation (-0.545) between tuber yield per plant and tuber number per plant was recorded. This may be attributed to the negative relationship between the tuber number and tuber weight (Maris 1969) while tuber weight has been reported to be a decisive factor in determining tuber yield in potato (Semenova and Goncharova ,1984).

Although there was a positive association between these characters at genotypic level, the result was again low magnitude. This is in contrast to the findings of Maris (1969) who observed positive association between tuber dry matter and tuber yield which could be due to the differences in testing materials and growing environmental conditions (Beukema and Vaanderzag, 1979).

The correlation coefficient between tuber yield and tuber protein content was positive but non significant (r = 0.134). Tuber protein content also had a low positive and medium negative correlation with other characters. According to this finding, improvement in tuber protein content could result in a weak selection for tuber yield and other economically important characters. In light of the above, it is evident that the tuber yield per plant had high magnitude positive association with haulm dry weight and average tuber weight at both phenotypic and genotypic levels. Tuber yield per plant also had considerably high positive correlation with leaf area and leaf area index while high magnitude of negative association with tuber number per plant at genotypic level (Table 3).

At phenotypic level, significant correlations among some of the characters other than their association with tuber yield per plant were also observed. Tuber dry matter recorded highly significant positive correlation with tuber specific gravity (r = 0.455). This implied that any increase in tuber specific gravity would lead to increase in tuber dry matter production and starch contents which corroborated the findings of Scheele *et al.,(*1937) and Rasul *et al* 1995. Pointing out that tuber specific gravity is an indicator of tuber dry matter and starch contents. At genotypic level Positive correlation between tuber dry matter and tuber specific gravity (r=1.302), stem number per plant (r=0.367), leaf area(r=0.332) and leaf area index (r = 0.428). Similarly, there was also positive correlation, of high magnitude between tuber specific gravity and days to flowering (r =0.831), days to maturity (r = 0.382), haulm dry weight (r = 0.393), stem number per plant (r = 0.733), leaf area (r = 0.499) and leaf area index (r = 0.529) This suggested that any improvement in the vegetative growth parameters and aspects like days to flowering, days to maturity and haulm dry weight could lead to improvement in tuber dry matter production. This is in agreement with the findings of Kaminski (1977).

Table 3. Estimation of correlation coefficients at genotypic (above diagonal) and phenotypic (below diagonal) levels among thirteen characters

	PH	SNPP	LA	LAI	DTF	DTM	HDW	TNPP	TYPP	**ATW**	**TSG**	**TDM**	**TPC**
PH	1	-0.049	0.603++	0.523++	0.214	-0.124	0.30	-0.077	0.164	0.020	0.008	-0.092	0.059
SNPP	-0.038	1	-0.127	-0.143	0.438+	0.271	0.057	-0.171	-0.149	-0.182	0.733++	0.368+	-0.356
LA	0.432*	0.099	1	1.013++	0.523	0.517++	0.834++	0.160	1.539++	0.186	0.50++	0.333	0.185
LAI	0.417*	0.094	0.959**	1	0.509++	0.426++	0.903++	0.161	1.378++	0.146	0.529++	0.429	0.166
DTF	0.101	0.128	0.210	0.222	1	0.789++	0.315	0.845++	0.231	-0.753++	0.831++	0.228	-0.301
DTM	-0.035	0.125	0.149	0.205	0.171	1	0.657++	0.015	0.155	-0.039	0.382+	0.091	-0.026
HDW	0.311	0.102	0.534**	0.631**	0.146	0.396*	1	-0.098	0.954++	0.348	0.394+	0.178	0.151
TNPP	-0.625	0.253	0.028	0.020	0.322	-0.022	-0.068	1	-0.545	-0.939++	0.208	0.299	-0.269
TYPP	0.083	-0.060	0.146	0.202	-0.175	0.269	0.443*	0.0587	1	0.708++	-0.195	0.151	0.134
ATW	0.052	-0.225	-0.225	0.031	-0.465	0.151	0.308	-0.743	0.532**	1	-0.329	-0.318	0.266
TSG	0.043	0.146	0.086	0.113	0.455	0.217	0.158	-0.039	0.07	-0.035	1	1.303++	-0.046
TDM	-0.092	0.123	0.060	0.097	0.146	-0.068	0.095	0.069	-0.155	-0.241	0.455**	1	·0.178
TPC	-0.007	-0.252	0.072	0.069	-0.133	0.162	0.102	-0.173	0.056	0.188	0.005	-0.175	1

***,* indicate Significant at 1% and 5% probability level respectively; +, ++ indicate the magnitude of genotypic correlation coefficientCorresponding to the phenotypic correlation significant at1% and 5% probability level respectively.PH=Plant Height, SNPP = Stem Number per Plant, LA= Leaf Area, LAI=Leaf Area Index, DTF= Days to Flowering, DTM= days to maturity HDM =* Hlaum dry weight TNPP=Tuber Number Per Plant, TYPP= Tuber Yield Per Plant, ATW=AverageTuberWeight,,TSG=Tuber,SpecificGravity, T=Tube

In this study, the observed correlations indicated, that it might be possible to exploit the characters, like stem number per plant, leaf area, leaf area index, haulm dry weight and tuber specific gravity in efforts to improve tuber dry matter in view of the positive correlation between pairs of characters. Such an approach could lead to correlated responses to selection that with the increase in one may be followed by increment of the other. Negative correlation between tuber specific gravity with average tuber weight and that of average tuber weight with tuber dry matter observed in the present study might preclude the simultaneous improvement of these characters along with each other.

Path Coefficient Analysis

In order to determine the relative magnitude of various characters contributing to correlations, the observed genotypic correlations were further partitioned in to their components by path coefficient analysis. Tuber yield being the complex out come of different characters was considered to be the resultant variable while the rest of the characters were the causal variables.

At genotypic level the path analysis revealed that average tuber weight had maximum positive direct effect (3.546) followed by tuber number per plant (3.114), leaf area (2.261) days to maturity (1.006), tuber dry matter (0.742) and plant height (0.703) on tuber yield per plant (Table 4). This seems to suggest that these characters are good contributors to tuber yield per plant. These results are in agreement with those of Kaminski (1977), Maris (1969), Naik *et al,* (1998) and Sandhu and Kang (1998) but are at variance with those of Werner *et al* (1998) in respect of days to maturity and plant height exhibiting negative direct effects on tuber yield. This could be attributed to the differences in the testing materials, potential growing period and other aspects of potato physiology influenced by growing and environmental conditions (Beukema and Vanderzaag, 1979).

The data on genotypic path analysis indicated that leaf area index (-2.447) had maximum negative direct effect followed by days to flowering (-0.618), stem number per plant (-0.514) and haulm dry weight (-0.489) on tuber yield per plant (Table 4). The leaf area exhibiting the third maximum positive direct effect on tuber yield per plant in the study (Table5) also had high positive genetic correlation with tuber yield (Table 3) but it was found to influence unfavorably through its negative indirect effect *via* leaf area index (-2.48). The character showing maximum positive direct effect (average tuber weight) also exerted positive indirect effect *via* days to flowering (0.465) but days to flowering posed negative direct effect on tuber yield (-0.618) and high magnitude negative indirect effect *via* average tuber weight (-2.699). Similarly average tuber weight *via* leaf area index exerted negative indirect effect while leaf area index posed high magnitude negative direct effect (-2.477) but it posed considerable positive indirect effect *via* average tuber weight (0.515). These highlighted the need for appropriate care in exercising selection for these characters.

Favorable indirect effect on tuber yield per plant was observed for tuber dry matter *via* tuber specific gravity (0.967). Average tuber weight besides exerting maximum positive direct effect on tuber yield per plant (Table4), also showed favorable indirect influence *via* leaf area, and days to flowering. Plant height having positive direct effect also recorded favorable indirect effects on tuber yield *via* leaf area. This is substantiated by the observations of Maris (1969) who concluded that greater plant heights are not only important for total tuber yield but also for mean tuber weight. Days to flowering in spite *of* having negative direct effect on tuber yield per plant had positive indirect effect *via* leaf area, days to maturity and tuber number per plant thereby contributing to positive genetic correlation though of low magnitude to tuber yield per plant. Leaf area index, days to flowering and haulm dry weight though had negative direct effects on tuber yield per plant (Table.4) indicated positive genotypic correlation (Table 3).

Singh and Chaudhary (1985) observed that if the correlation coefficient is positive but the direct effect is negative or negligible, then the causal factors of indirect effects seem to be the cause of correlation. In light of this observation, indirect causal factors, leaf area index *via* plant height, leaf area, days to maturity, tuber number per plant, average tuber weight and tuber dry matter; days to flowering *via* leaf area, days to maturity, tuber number per plant and haulm dry weight *via* leaf area, days to maturity and average tuber weight need to be given appropriate focus in selection for higher tuber yield per plant. Similar view is held by Kaminski (1977). Tuber number per plant however, exhibited negative genotypic association (Table 3) but exerted high positive direct effects on tuber yield per plant. This pointed out to the fact that contrasting roles of negative indirect effects of this character have to be considered in improving tuber yield per plant. Stem number per plant exhibited high negative direct effect and negative genotypic association with tuber yield per plant (Table 3). This in turn highlighted the contrasting roles of both direct as well as indirect effects of this character on tuber yield per plant.

The study brought out a positive residual effect of 0.5376 indicating that only 46.24 per cent of the genetic variability is being accounted for by the characters considered. In view of this, it would be worthwhile to consider some more characters viz; potential growing period, photosynthetic efficiency, assimilation rate, growth rate of tuber, rate of bulking and tuber size in future studies in order to better account for the variability prevailing among the test genotypes.

Table.4. Estimates of direct (bold –diagonal values) and indirect effects at genotypic level of 12 characters on tuber yield

	PH	SNPP	LA	LAI	DTF	DTM	HDW	TNPP	ATW	TSG	TDM	TPC	r_g
PH	0.703	0.025	1.363	-1.280	-0.132	-0.125	-0.147	-0.240	0.073	0.002	-0.069	-0.009	0.164
SNPP	-0.034	-0.514	-0.288	0.351	-0.27	0.272	-0.028	0.533	-0.647	0.149	0.273	0.054	-0.149
LA	0.424	0.065	2.261	-2.48	-0.323	0.52	-0.408	0.499	0.661	0.101	0.247	-0.028	1. 539
LAI	0.368	0.074	2.292	-2.447	-0.314	0.429	-0.442	0.503	0.515	0.107	0.318	-0.025	1.378
DTF	0.15	-0.225	1.183	-1.245	-0.618	0.794	-0.154	2.632	-2.669	0.168	0.169	0.047	0.232
DTM	-0.087	-0.139	1.169	-1.042	-0.488	1.006	-0.321	0.046	-0.137	0.076	0.068	0.004	0.155
HDW	0.211	-0.029	1.886	-2.210	-0.195	0.661	-0.489	-0.305	1.235	0.080	0.132	-0.023	0.954
TNPP	-0.054	-0.088	0.362	-0.395	-0.522	0.015	0.048	3.114	-3.330	0.042	0.222	0.041	-0.545
ATW	0.014	0.094	0.421	-0.356	0.465	-0.039	-0.170	-2.924	3.456	-0.066	-0.236	-0.041	0.708
TSG	0.005	-0.377	1.131	-1.295	-0.514	0.384	-0.193	0.646	-1.159	0.203	0.967	0.007	-0.195
TDM	-0.065	-0.189	0.753	-1.048	-0.141	0.092	-0.087	0.931	-1.128	0.264	0.742	0.027	0.151
TPC	0.041	0.183	0.418	-0.407	0.186	-0.026	-0.074	-0.838	0.945	-0.009	-0.132	-0.153	0.134

r_g = genotypic correlation coefficient
Residual effect = 0.5376
PH=Plant Height, SNPP = Stem Number Per Plant, LA= Leaf Area, LAI=Leaf Area Index, DTF= Days to Flowering, DTM= Days to Maturity, HDW = Haulm Dry Weight, TNPP=Tuber Number Per Plant, TYPP= Tuber Yield Per Plant, ATW= Average Tuber Weight, TSG=Tuber Specific Gravity, TDM = Tuber Dry Matter, TPC= Tuber Protein Content

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Appendix I: Mean values of various characters of the genotypes

Treatments	PH	SN	LLI	LA	LAI	DTF	DTM	HDW	TN	TY	TW	TSG	TDM	TPC
AL-100	67.7	6.5	1.6	1.2	5.2	36.3	77.0	35.9	15.2	702.3	48.1	1.11	26.67	5.40
AL-105	70.5	2.9	1.3	1.1	4.8	33.3	76.0	29.0	9.9	643.5	66.1	1.06	24	8.7
AL-204	44.9	6.0	1.4	0.8	3.6	37.0	82.0	30.67	8.2	687.6	83.6	1.09	24.133	8.1
AL-207	61.7	5.4	1.6	0.9	4.4	35.0	75.3	32.9	10.7	536.9	51.5	1.10	26.0	10.6
AL-216	60.3	5.9	1.4	0.9	4.1	33.7	73.7	27..3	13.5	757.6	55.8	1.11	26.33	10.2
AL-256	60.3	4.7	1.6	0.9	4.3	33.0	83.7	35.2	10.6	689.7	64.6	1.10	25.73	11.2
AL-268	59.3	5.4	1.6	1.1	5.0	34.7	81.0	33.3	9.5	624.8	67.3	1.11	27.07	10.5
AL-348	62	5.0	1.4	1.0	4.7	37.0	75.3	33.3	12.4	640.8	53.5	1.12	27.733	5.4
AL-350	58.3	4.0	1.6	0.8	3.5	33.3	84.0	30.8	9.9	660.7	67.7	1.11	25.87	5.5
AL-471	59.1	5.1	1.5	0.9	4.0	39.3	73.7	25.2	12.3	579.7	50..8	1.10	24.67	10.2
AL-450-5	28.5	4.9	1.4	0.9	4.0	40.0	92.7	35.2	13.2	625.9	48.2	1.12	29.47	11.6
AL-456-1	59.6	5.7	1.5	1.1	4.8	34.0	78.3	35.5	8.7	635.6	73.9	1.11	26.67	10.2
AL-406-B	59.6	5.0	1.2	1.2	5.3	33.3	78.3	42.8	10.5	703.2	67.1	1.08	26.33	11.5
AL-560	61.9	3.3	1.6	1.0	4.6	34.0	76.0	27.3	10.8	697.8	65.7	1.10	23.47	10.1
AL-517	59.9	5.3	1.5	0.8	3.5	36.0	81.3	27.3	9.2	632.4	68.9	1.11	27.33	10.3
AL-567	60.7	3.7	1.5	0.9	4.0	35.7	75.3	32	11.5	715.3	61.6	1.10	24.00	10.6
AL-556	55.5	5.1	1.4	1.0	4.5	34.3	81.0	33.5	10.9	655.3	61.0	1.10	25.47	11.3
AL-624-5	63.9	6.8	1.6	1.2	5.4	39.7	82.0	46.5	10.9	734.0	68.9	1.05	21.733	7.3
CIP386029-18A	60.00	5.6	1.6	0.9	4.3	39.0	80.0	41	11.9	717.2	64.5	1.10	25.067	7.1
CI382121-6	68.4	3.5	1.5	1.1	5.0	37.3	87.3	38	11.7	541.6	46.1	1.10	24.4	11.6
CIP387146-6	59.3	4.2	1.4	1.3	7.0	40.0	84.3	88.5	11.4	829.7	73.9	1.11	28.53	10.0
CIP-378570-4B	81.2	3.8	1.3	0.7	3.2	29.7	77.0	37.9	7.2	598.6	96.5	1.08	21.2	12.2

CIP-377838-1	25.2	3.3	1.5	0.65	2.55	41	68.7	16.1	8.5	664.3	112.4	1.06	23.87	10.2
CIP-381403-5	67.6	4.3	1.3	1.5	6.8	31.3	91.3	72	8.3	1008.9	122.2	1.09	23.2	11.8
CIP-378194-28	65.7	6.1	1.6	1.0	4.5	30.3	81.7	55.1	7.5	726.4	97.5	1.09	24.27	11
CIP-386029-18B	49.5	3.5	1.5	0.9	4.0	40.0	83.0	32.5	10	788.1	78.0	1.09	24.13	10.7
CIP-378370-12A	42.1	5.8	1.4	0.7	3.0	40.0	85.7	31.2	14.9	558..6	38.5	1.09	22.8	8.6
CIP-702867-51NB	56.4	4.4	1.3	1.2	5.4	40.3	80.00	43.2	10.1	730.8	73.2	1.1	25.6	11.2
AL-111	63.2	2.9	1.5	1.4	6.2	35.3	73.7	34.9	11.3	783.6	68.8	1.09	23.73	11.5
AL-114	55.8	4.2	1.6	0.8	3.7	36.3	73.7	31.1	17.2	629.3	37.9	1.06	23.87	10.2
S.E.M ±	3. 9	0.8	0.13	0.21	0. 9	4.1	5. 3	4.00	1.6	103.4	9.7	0.03	1.24	1.20
L.S.D	10.45	2.14	0. 35	0. 54	2.41	10. 99	14. 2	10. 72	6. 97	277. 1	25. 99	0.1	3. 32	3.22
C.V (%)	8.1	20.49	10. 80	26. 04	25.4	14.22	8.05	13. 22	18. 28	18. 53	17. 44	2. 20	6. 08	14. 44

PH=Plant Height, SNPP = Stem Number Per Plant, LA= Leaf Area, LAI=Leaf Area Index, DTF= Days to Flowering, DTM= days to maturity HDW= Haulm Dry Wight, TNPP=Tuber Number Per Plant, TYPP= Tuber Yield Per Plant, ATW= Average Tuber Weight, TSG=Tuber Specific Gravity, TDM = tuber dry matter, TPC= Tuber Protein Content

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